ORDER

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6365.1A

1/3/83

SUBJ: U.S. NATIONAL AVIATION STANDARD FOR THE MODE SELECT BEACON SYSTEM (MODE S)

1. PURPOSE. This order establishes the U.S. National Aviation Standard for the *Mode Select Beacon System (Mode S) which defines the performance requirements of the Mode S system. *

2. DISTRIBUTION. The order is distributed to the director level in Washington with a division level distribution in the Acquisition and Materiel, Air Traffic, Program Engineering and Maintenance, and Systems Engineering Services, the Offices of Airworthiness, Flight Operations, and Budget; to the director level in the regions, with division level distribution in Air Traffic, Airway Facilities, and Flight Standards Divisions; to the director level at the Aeronautical Center with division level distribution to the FAA Depot; and to the director level at the FAA Technical Center with division level distribution in the Systems Test and Evaluation and Systems Simulation and Analysis Divisions.

3. CANCELLATION. Order 6365.1, U.S. National Aviation Standard for the Discrete Address Beacon System (DABS), dated December 9, 1980, is cancelled.

4. BACKGROUND.

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a. It was recognized in a study conducted for the Department of Transportation in 1968, that improvements would be required in the Air Traffic Control Radar Beacon System (ATCRBS) to support air traffic control through the 1990's. Also recognized was the need for a data link system to support enhanced automation with sufficient capacity to meet traffic growth through the same period.

b. The concept that emerged was a discrete address beacon system with an integral data link. Order 6365.1 established the U.S. National Aviation Standard for that concept.

c. In December 1981 the concept was modified to remove all ground based collision avoidance functions and associated complexities reducing cost substantially. The name was changed to Mode S at that time to be consistent with the international name adopted for these systems. *

Distribution: A-W-1 (minus AT/WS/FO/BU/LG/PM/ES); A-W (AT/WS/FO/BU/LG/PM/ES)-2; A-X-1 (minus AT/AF/FS); A-X (AT/AF/FS)-2; A-Y-1 (minus DE); A-Y (DE)-2; A-Z-1 (minus SS/ST); A-Z (SS/ST)-2

Initiated By: APM-320

* d. Mode S is similar to the existing Air Traffic Control Radar Beacon System (ATCRBS) in the sense that the ground station transmits interrogations to and receives replies from cooperative airborne transponders. A principal feature of Mode S is that each aircraft is assigned a unique address code. Using this unique code, interrogations can be directed to a particular aircraft, and replies unambiguously identified. Channel interference is minimized because the Mode S ground station can limit its interrogations to targets of interest. In addition, by proper timing of interrogations, replies from closely spaced aircraft can be received without mutual interference. The unique address in each interrogation and reply also permits the inclusion of data link messages to or from a particular aircraft.

e. The capability for an evolutionary transition from ATCRBS to Mode S has been achieved by providing a high degree of compatibility between Mode S and ATCRBS. Mode S uses the same interrogation and reply frequencies as ATCRBS. In addition, the Mode S ground station performs the ATCRBS functions as well as the Mode S functions. This degree of compatibility permits a smooth transition in which Mode S ground stations provide surveillance of ATCRBS equipped aircraft and Mode S transponders reply to ATCRBS ground stations.

f. Thus, Mode S provides improved surveillance of Mode S and ATCRBS equipped aircraft and data link service to Mode S aircraft as an integrated system. Since Mode S has been designed as an evolutionary replacement for the current ATCRBS, it can be introduced into the present ATCRBS environment without impacting present ATCRBS services. *

5. SCOPE. Appendix 1, U.S. National Aviation Standard for the Mode Select Beacon System (Mode S), shall be used as the basic document for defining the technical parameters, tolerances, and performance of all Mode S components.

6. POLICY. Subject to applicable rulemaking, programming, and budgetary procedures, the National Airspace System will utilize Mode S as the primary data acquisition source for aircraft position, identity, and pressure-altitude data. In addition, it is planned that its integral data link communications capability will be utilized in support of aircraft separation assurance, increased levels of automation for air traffic control, and transfer of other information to enhance flight safety.

7. CHANGES TO THIS ORDER. The Director, Program Engineering and Maintenance Service, is authorized to issue changes in the appendix of this order.

Helms

J. Lynn Helms
Administrator

U.S. NATIONAL AVIATION STANDARD
FOR THE
MODE SELECT BEACON SYSTEM

Appendix 1 to Order 6365.1A

CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

CONTENTS (CONT'D)

CONTENTS (CONT'D)

CONTENTS (CONT'D)

CONTENTS (CONT'D)

U.S. NATIONAL AVIATION STANDARD FOR THE MODE S BEACON SYSTEM

1. GENERAL.

1.1 System Features.

1.1.1 The Function of Mode S.

Mode S is an improved secondary radar system with an integral two-way data link. Mode S adds to the Air Traffic Control Radar Beacon System (ATCRBS) the manner of selecting which aircraft will respond to an interrogation. In ATCRBS, the selection is spatial; in Mode S, each aircraft is assigned a unique address code. Thus, an interrogator is able to limit responses to its interrogations to those aircraft for which it has surveillance responsibility, and to time the interrogations to ensure that the responses from Mode S-equipped aircraft do not overlap. In addition, the discrete address provides the basis for a ground-air-ground and air-to-air digital data link. The main requirements for Mode S are to:

a. Support automated air traffic control (ATC) with improved surveillance and communication capability and reliability in the projected 1995 traffic environment.

b. Permit evolutionary implementation.

1.1.2 Rationale for the Mode S National Standard.

1.1.2.1 Legal Rationale.

Under the Federal Aviation Act as amended 49 U.S.C 1353 (c), the Department of Transportation has the responsibility for the development and operation of a common system of air traffic control and navigation for both military and civil aircraft. Explicitly, the Secretary shall develop, modify, test and evaluate systems, procedures, facilities, and devices, as well as define the performance characteristics thereof, to meet the needs for safe and efficient navigation and traffic control of all civil and military aviation, except for those needs of military agencies which are peculiar to air warfare and primarily of military concern.

1.1.2.2 Technical Rationale.

Systems selected for implementation as a result of these developments, modifications, test and evaluation efforts are described in U.S. National Aviation Standards. These are system standards embodying descriptions of system characteristics. They describe technical parameters and tolerances that ensure proper operation and compatibility between elements of the National Airspace System and in an environment which includes authorized radiating elements of other systems.

1.1.2.3 Conclusion.

Optimum performance will be obtained if these System Characteristics are met by all users of the Mode S System under all expected operating conditions. Consequently, it is important to define many characteristics of the airborne components used in the system.

1.2 Coordination of Mode S with the Air Traffic Control Radar Beacon System (ATCRBS).

1.2.1 ATCRBS Compatibility.

To facilitate the introduction of Mode S into the ATCRBS system, both ground and airborne Mode S installations include full ATCRBS capability. Mode S interrogators provide surveillance of ATCRBS-equipped aircraft, and Mode S transponders are capable of replying to ATCRBS interrogators. To accomplish this dual mode operation (ATCRBS and Mode S) with minimum equipment complexity, Mode S operates on the same interrogation and reply frequencies as ATCRBS.

1.2.2 Relationship Between Mode S and ATCRBS National Standards.

ATCRBS transponders are not affected by the Mode S National Standard, and the ATCRBS-mode operation of Mode S transponders adheres to the ATCRBS National Standard (Reference A) for Modes A and C.

1.2.3 ATCRBS IFF Mark XII System (AIMS) Compatibility.

The Mode S system has been designed for operational compatibility with AIMS including Mode 4.

1.3 Scope of this Standard.

This document describes and standardizes the characteristics of the Mode S Beacon System.

1.3.1 Items Not Covered.

This Standard does not prescribe the features and capabilities of Mode S transponders that must be implemented for operation in Mode S airspace nor does it include specific data link message contents and codes that may later be associated with various separation assurance (collision avoidance) and data interchange services supported by Mode S. Such characteristics will be the subject of separate documentation. All operational applications of Mode S messages must be standardized, and no experimental or ad hoc applications may be implemented without prior approval of the Federal Aviation Administration.

1.4 Overall System Capabilities.

1.4.1 Coverage.

The Mode S sensor (interrogator) performs surveillance of all beacon-equipped aircraft within its line-of-sight coverage airspace. The nominal maximum range is 200 nmi, but is site adaptable to shorter and longer (up to 255 nmi) ranges. ATCRBS-equipped aircraft are interrogated at the minimum rate that produces an adequate number of replies for azimuth determination. The addresses of Mode S-equipped aircraft are acquired by means of an All-Call interrogation, or by means of ground-to-ground handover. After acquisition, Mode S-equipped aircraft are interrogated with their unique address call. For both ATCRBS and Mode S-equipped aircraft, azimuth is determined by a monopulse technique. System coverage for both ATCRBS and Mode S targets is intended to be identical to that described in paragraph 1.3.2 of reference A.

1.4.2 Data Link.

The Mode S sensor provides a two-way digital data link for all Mode S-equipped aircraft. Messages originating on the ground are sent to suitably equipped aircraft and appropriate acknowledgment received is relayed to the sender. The Mode S sensor also manages the data link so that when an aircraft wishes to initiate an air-to-ground message, that message is read out with minimum delay.

1.4.3 Link Reliability.

High link reliability is achieved by design features intrinsic to the Mode S system. Reinterrogation reduces link failure caused by interference. Signal formats, differential phase shift keying (DPSK) on the uplink and pulse position modulation (PPM) with error correction capability on the downlink, provide high link reliability in a pulse interference environment. Discrete addressing eliminates synchronous interference for Mode S-equipped aircraft.

1.5 Glossary of Acronyms

ATC: Air Traffic Control
ATCRBS: Air Traffic Control Radar Beacon System
TCAS: Traffic Alert and Collision Avoidance System

1.6 References.

Reference A: "U.S. National Aviation Standard for the IFF Mark X (SIF)/Air Traffic Control Radar Beacon System Characteristics", Attachment 1 to DOT/FAA Order 1010.51A, 8 March 1971.

2. SIGNALS IN SPACE.

Note: This section describes all rf characteristics of the Mode S signals. The interrogator signals are described as they can be expected to appear at the antenna of the transponder. Because signals can be corrupted in transmission, tolerances for interrogator transmissions are more restrictive than described here and should not be derived from this section. Interrogator rf waveform tolerances are described in section 6 of this document.

2.1 Mode S Frequencies.

The carrier frequency of Mode S interrogations (uplink) is 1030 ± 0.01 MHz. The carrier frequency of Mode S replies (downlink) is 1090 ± 3 MHz for aircraft flying below 15,000 feet and is 1090 ± 1 MHz for aircraft flying above that level.

Note: The carrier frequencies are identical to those used in ATCRBS and specified in ref. A. The frequency tolerance for the Mode S interrogation is tighter than for ATCRBS in order to accommodate phase shift modulation; aircraft which operate above 15000 ft hold the reply frequency tolerance to ± 1 MHz to improve the monopulse azimuth estimation accuracy for long-range sensors.

2.1.1 Polarization.

Vertical polarization is used in Mode S transmissions.

2.2 Mode S Modulation.

The modulation of Mode S carrier frequencies consists of pulses some of which have internal phase modulation.

2.2.1 Pulse Shapes.

Pulse shapes are defined as described in ref. A, section 2.

2.2.1.1 Pulse Shapes, Interrogations.

The specifications for pulse shapes used in Mode S interrogations are summarized in the following table. All values are in microseconds.

Pulse Designator	Pulse Duration	Duration Tolerance	Rise Time Min.	Rise Time Max.	Decay Time Min.	Decay Time Max.
P_1, P_2, P_3, P_5	0.8	± 0.1	0.05	0.1	0.05	0.2
P_4 (short)	0.8	± 0.1	0.05	0.1	0.05	0.2
P_4 (long)	1.6	± 0.1	0.05	0.1	0.05	0.2
P_6 (short)	16.25	± 0.25	0.05	0.1	0.05	0.2
P_6 (long)	30.25	± 0.25	0.05	0.1	0.05	0.2

Note: The 0.8-microsecond pulses used in Mode S interrogations are identical in shape to those used in ATCRBS and described in ref. A, 2.4.5.

2.2.1.2 Pulse Shapes, Replies.

The specifications for pulse shapes used in Mode S replies are summarized in the following table. All values are in microseconds.

Pulse Duration	Tolerance	Rise Time Min.	Rise Time Max.	Decay Time Min.	Decay Time Max.
0.45	± 0.1	0.05	0.1	0.05	0.2
0.5	± 0.05	0.05	0.1	0.05	0.2
1.0	± 0.05	0.05	0.1	0.05	0.2

Note: The 0.45-microsecond pulses are used for replies to ATCRBS Interrogations and are listed here only for convenience. The (identical) specifications of ref. A, 2.6 apply.

2.2.2 Phase Modulation.

The short (16.25-microsecond) and long (30.25-microsecond) P_6 pulses of 2.2.1.1 have internal modulation consisting of 180-degree phase reversals of the carrier at designated times.

2.2.2.1 Phase Reversal Duration.

The duration of the phase reversal is less than 0.08 microsecond as measured between the 10-degree and 170-degree points of the phase transition. The interval between the 80 percent points of the amplitude transient associated with the phase reversal is less than 0.08 microsecond.

2.2.2.2 Phase Relationship.

The tolerance on the 0 or 180 degree phase relationship between successive chips within the P_6 pulse (including the sync phase reversal) is ± 5 degrees.

Note: A "chip" is the shortest carrier interval between possible data phase reversal locations assigned as indicated in Fig. 2.3-2.

2.3 Pulse and Phase Reversal Sequences.

Specific sequences of the pulses or phase reversals described in 2.2 constitute interrogations and replies.

2.3.1 ATCRBS Interrogations.

The ATCRBS interrogation waveforms are defined in ref. A, 2.4.

2.3.2 ATCRBS/Mode S All-Call and ATCRBS-Only All-Call Interrogations.

These interrogation waveforms consist of three pulses: P_1, P_3, and P_4 as shown in Fig. 2.3-1. One or two control pulses (P_2 alone, or P_1 and P_2) are transmitted using a separate antenna pattern to suppress responses from aircraft in the sidelobes of the interrogator antenna.

2.3.2.1 Pulse Definitions and Spacings.

P_1, P_2, and P_3 have shapes and spacings as defined in ref. A, 2.4. P_4 is either a 0.8-microsecond pulse or a 1.6-microsecond pulse (2.2.1.1) and occurs 2 ± 0.05 microseconds after P_3, measured from leading edge to leading edge.

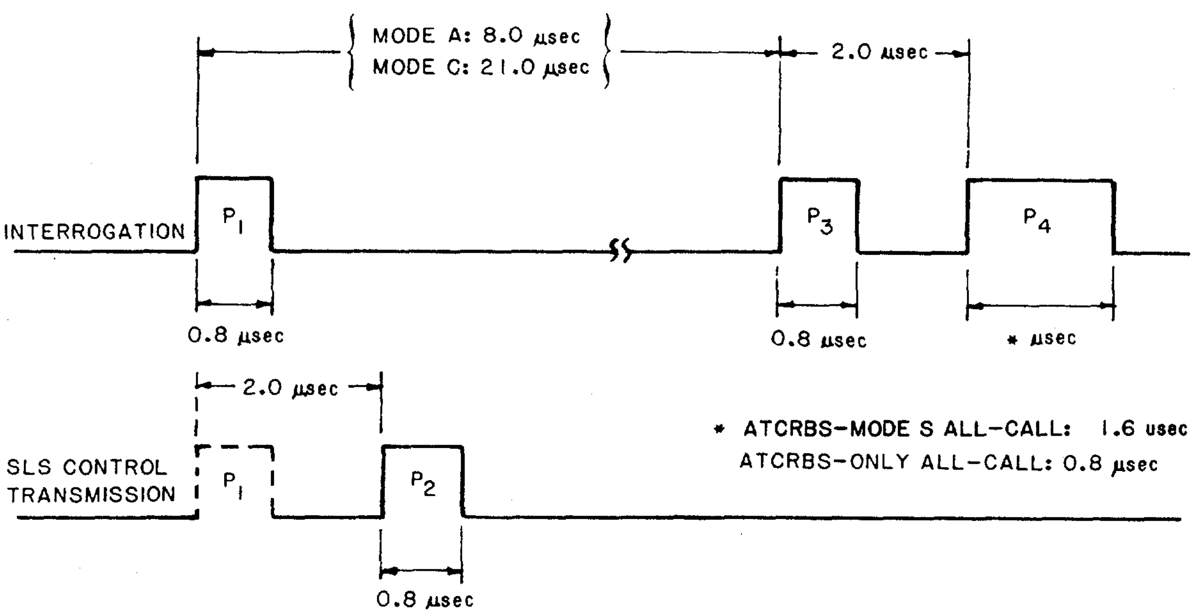


Fig. 2.3-1. ATCRBS/Mode S and ATCRBS-Only All-Call Interrogation Pulse Sequence.

2.3.2.2 Pulse Levels.

Relative levels between pulses P_1, P_2, and P_3 are in accordance with ref. A, 2.5.

The radiated amplitude of P_4 is within 1 dB of the radiated amplitude of P_3.

Note: P_1, P_2 and P_3 are 0.8-microsecond pulses. Spacings: $P_1 - P_2 = 2 \pm 0.15$ microseconds; $P_1 - P_3 = 8$ or 21 ± 0.2 microseconds. Levels: $P_1 - P_2$ see ref. A, 2.5.1; $P_1 - P_3$ = within 1 dB. ATCRBS/Mode S All-Call and ATCRBS-Only All-Call interrogations correspond in their pulse sequence to the ATCRBS interrogations of ref. A, 2.4. The additional P_4 pulse is not seen by ATCRBS transponders, which reply as usual. Mode S transponders recognize the long P_4 of the ATCRBS/Mode S All-Call interrogation and reply with a Mode S format. Mode S transponders recognize the short P_4 of the ATCRBS-Only All-Call interrogation and do not accept such interrogations.

2.3.3 Mode S Interrogations.

The Mode S interrogation sequence consists of three pulses: P_1, P_2, and P_6 as shown in Fig. 2.3-2. A control pulse, P_5, is transmitted with the Mode S-only All-Call using a separate antenna pattern to suppress acceptance of the interrogation by aircraft in the sidelobes of the interrogator antenna. P_5 may also be transmitted with other Mode S formats.

Note: The $P_1 - P_2$ pair preceding P_6 suppresses replies from ATCRBS transponders to avoid synchronous garble caused by random triggering of ATCRBS transponders by the Mode S interrogation.

A series of chips containing the information within P_6 starts 0.5 microsecond after the sync phase reversal. Each chip is of 0.25-microsecond duration and is preceded by a possible phase reversal. If preceded by a phase reversal, a chip represents a logic "1". There are either 56 or 112 chips. The last chip is followed by a 0.5-microsecond guard interval which prevents the trailing edge of P_6 from interfering with the demodulation process.

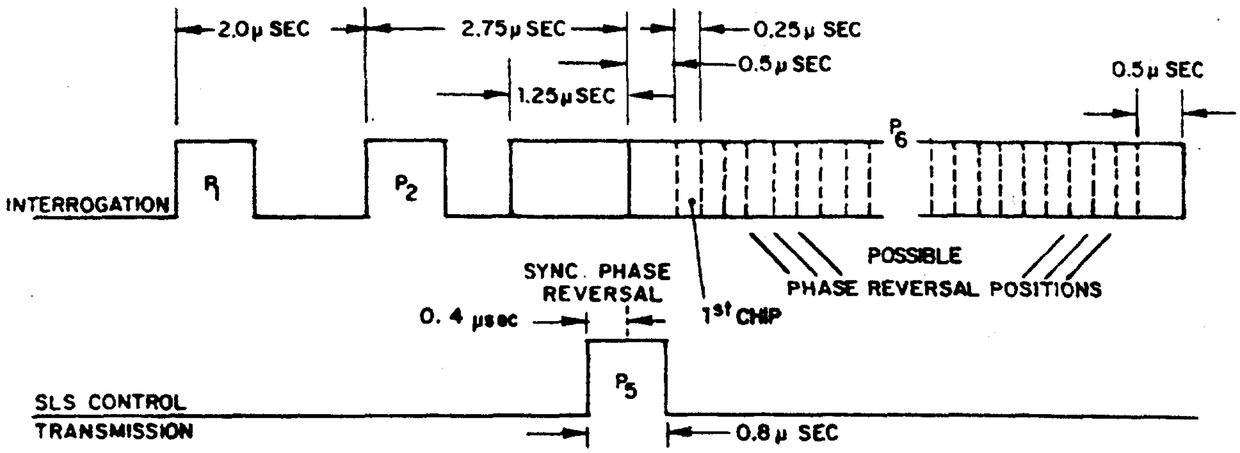


Fig. 2.3-2. Mode S Interrogation Pulse Sequence.

2.3.3.1 Pulse Definition.

P_1, P_2, and P_5 are 0.8-microsecond pulses. P_6 is either a 16.25-microsecond or a 30.25-microsecond pulse (2.2.1.1) containing phase reversals.

2.3.3.2 Sync Phase Reversal.

The first phase reversal in the P_6 pulse is the Sync Phase Reversal.

Note: The sync phase reversal is the timing benchmark for succeeding transponder operations.

2.3.3.3 Data Phase Reversals.

The 90-degree point of each following data phase reversal can occur only at a time (N x 0.25) ± 0.02 microseconds (N > 2) after the Sync Phase Reversal.

Note: 56 or 112 data phase reversals can occur in the 16.25-and 30.25-microsecond P_6 pulses respectively. This results in a 4-Mb/sec data rate within the pulses.

2.3.3.4 Spacings.

Between leading edges the spacing from P_1 to P_2 is 2 ± 0.05 microseconds. The spacing from the leading edge of P_2 to the sync phase reversal of P_6 is 2.75 ± 0.05 microseconds. The leading edge of P_6 occurs 1.25 ± 0.05 microseconds before the sync phase reversal. P_5, if transmitted, is centered over the sync phase reversal such that the leading edge of P5 occurs 0.4 ± 0.1 microseconds before the sync phase reversal.

2.3.3.5 Pulse Levels.

The received amplitudes of P_2 and the initial first microsecond of P_6 are greater than the received amplitude of P_1 minus 0.25 dB. The envelope amplitude variation of P_6 is less than 1 dB and the amplitude variation between successive phase modulation chips in P_6 is less than 0.25 dB. P_5 is radiated with the same antenna pattern and amplitude as P_2 of 2.3.2.

Note: The phase reversals within P_6 define the information conveyed by the Mode S interrogation. The action of P_5 is automatic: Its presence, if of sufficient amplitude at the receiving location, masks the sync phase reversal of P_6 so that detection of P_6 cannot be accomplished.

2.3.4 ATCRBS Replies.

Mode S transponders reply to ATCRBS Mode A or Mode C interrogations with the waveforms described in ref. A, 2.6, unless inhibited by reply rate limiting or suppression.

2.3.5 Mode S Replies.

The Mode S reply waveform is shown in Fig. 2.3-3.

Note: Mode S replies consist of a four-pulse preamble followed by a series of pulses which carry either 56 or 112 information bits by means of pulse position modulation (PPM).

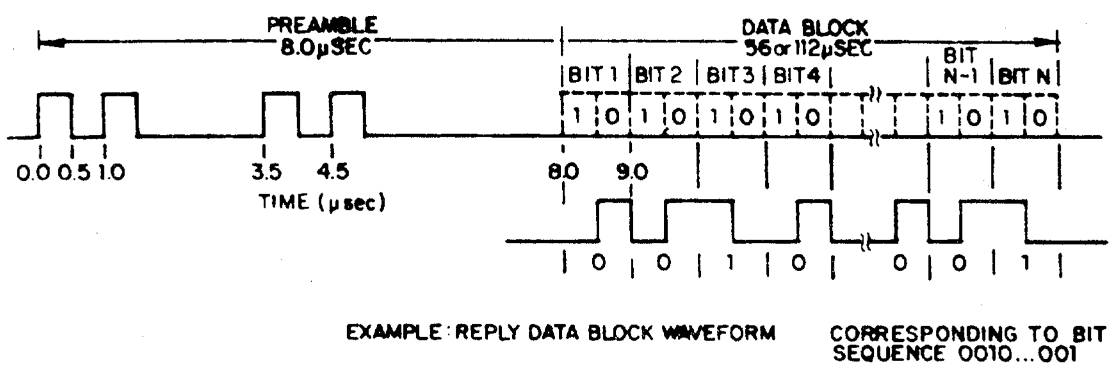


Fig. 2.3-3. Mode S Reply Waveform.

2.3.5.1 Pulse Definition.

All pulses in Mode S replies are either 0.5- or 1-microsecond pulses according to 2.2.1.2.

2.3.5.2 Pulse Spacings.

All reply pulses start at a defined multiple of 0.5 microseconds from the first transmitted pulse, measured between leading edges. The pulse position tolerance in all cases is ± 0.05 microseconds.

2.3.5.2.1 Reply Preamble.

The preamble consists of four 0.5-microsecond pulses. The second, third, and fourth pulses are spaced 1, 3.5, and 4.5 microseconds respectively from the first transmitted pulse.

2.3.5.2.2 Reply Data Pulses.

The block of reply data pulses begins 8 microseconds after the first transmitted pulse. Either 56 or 112 one-microsecond intervals are assigned to each transmission. A 0.5-microsecond pulse is transmitted either in the first or in the second half of each interval. If a pulse transmitted in the second half of one interval is followed by another pulse transmitted in the first half of the next interval, the two pulses merge and a 1-microsecond pulse (2.2.1.2) is transmitted.

2.3.5.3 Pulse Levels.

The pulse amplitude variation between one pulse and any other pulse in a Mode S reply does not exceed 2 dB.

2.4 Mode S Spectra.

Note: The emission spectrum of a Mode S transmission is concentrated around the carrier frequency.

2.4.1 Interrogation RF Spectrum.

The spectrum of a valid Mode S interrogation does not exceed the following bound.

Frequency difference (MHz from carrier)	Maximum Relative response (dB down from peak)
≥ 4 and < 6	6
≥ 6 and < 8	11
≥ 8 and <10	15
≥10 and <20	19
≥20 and <30	31
≥30 and <40	38
≥40 and <50	43
≥50 and <60	47
≥60	50

Note: The "worst case" spectrum is generated by a P_6 pulse which contains all possible phase reversals.

2.4.2 Reply RF Spectrum.

The spectrum of a valid Mode S reply does not exceed the following bound.

Frequency difference (MHz from carrier)	Maximum Relative response (dB down from peak)
>1.3 and < 7	3
>7 and <23	20
>23 and <78	40
>78	60

Note: The first column in this table does not include the reply carrier frequency tolerance (2.1).

3. SIGNAL CONTENT.

Note: This section describes the location and coding of the information contained in Mode S transmissions.

3.1 Data Blocks.

The interrogation and reply data blocks can contain either 56 or 112 bits.

3.1.1 Interrogation Data Blocks.

The interrogation data block consists of the sequence of 56 or 112 data chips located after possible data phase reversal locations within P6 (2.3.3.3). A 180-degree phase reversal of the carrier preceeding a chip characterizes that chip as a binary "one". No preceding phase shift denotes a binary "zero".

3.1.2 Reply Data Blocks.

The reply data block is formed by binary pulse position modulation encoding of the reply data as described in 2.3.5.2.2. A pulse transmitted in the first half of the interval represents a binary "one" while a pulse transmitted in the second half represents a binary "zero".

3.2 Format Structure, Interrogation and Reply.

The available coding space is occupied by either 56 or 112 bits of which 24 bits are used as the address of the aircraft while the rest are used for information transfer. A summary of interrogation and reply formats is presented in Figures 3.2-1 and 3.2-2.

3.2.1 Bit Numbering and Sequence.

The bits are numbered in order of their transmission, beginning with bit 1. If numerical values are encoded by groups (fields) of bits then the bit transmitted first is the most significant bit (MSB) unless otherwise stated.

Note: This rule need not apply to codes used in Mode S data link messages.

3.2.2 Fields.

Information is coded in fields which consist of at least one bit. In this document the decimal equivalent of the binary code formed by the bit sequence within a field is used as the designator of the field function or command.

Note: As an example, the 5-bit UF field is used to designate the uplink format type. The surveillance interrogation with identity is designated by a UF code of 00101. Since $00101_2 = 5_{10}$, this format is designated as UF=5.

Format No.	UF	
0	(0 0000)-3-(RL:1)--4--(AQ:1)--18--(AP:24).	Short Special Surveillance
1	(0 0001)---------------27-------------(AP:24)	
2	(0 0010)---------------27-------------(AP:24)	
3	(0 0011)---------------27-------------(AP:24)	
4	(0 0100)(PC:3)(RR:5)(DI:3)(SD:16)(AP:24).	Surveillance, Altitude Request
5	(0 0101)(PC:3)(RR:5)(DI:3)(SD:16)(AP:24).	Surveillance, Identity Request
6	(0 0110)---------------27-------------(AP:24)	
7	(0 0111)---------------27-------------(AP:24)	
8	(0 1000)---------------27-------------(AP:24)	
9	(0 1001)---------------27-------------(AP:24)	
10	(0 1010)---------------27-------------(AP:24)	
11	(0 1011)(PR:4)(II:4)(--19 one's--)(AP:24).	Mode S Only All-Call
12	(0 1100)---------------27-------------(AP:24)	
13	(0 1101)---------------27-------------(AP:24)	
14	(0 1110)---------------27-------------(AP:24)	
15	(0 1111)---------------27-------------(AP:24)	
16	(1 0000)-3-(RL:1)--4--(AQ:1)--18--(MU:56)(AP:24). .	Long Special Surveillance
17	(1 0001)---------------83--------------------(AP:24)	
18	(1 0010)---------------83--------------------(AP:24)	
19	(1 0011)---------------83--------------------(AP:24)	
20	(1 0100)(PC:3)(RR:5)(DI:3)(SD:16)(MA:56)(AP:24). .	Comm-A, Altitude Request
21	(1 0101)(PC:3)(RR:5)(DI:3)(SD:16)(MA:56)(AP:24). .	Comm-A, Identity Request
22	(1 0110)---------------83--------------------(AP:24)	
23	(1 0111)---------------83--------------------(AP:24)	
24	(11)(RC:2)(NC:4)(MC:80)(AP:24). .	Comm-C (ELM)

Notes: (1) (XX:M) denotes a field designated "XX" which is assigned M bits.
(2) ---N--- denotes free coding space with N available bits.
(3) For uplink formats (UF) 0 through 23 the format number corresponds to the binary code in the first 5 bits of the interrogation. Format number 24 is arbitrarily defined as the format beginning with "11" in the first two bit positions while the following three bits vary with the interrogation content.

Fig. 3.2-1. Overview of Mode S Interrogation Formats.

Format No.	DF	
0	(0 0000)(VS:1)-7-(RI:4)--2--(AC:13)(AP:24)	. . . . . Short Special Surveillance
1	(0 0001)---------------27--------------(AP:24)	
2	(0 0010)---------------27--------------(AP:24)	
3	(0 0011)---------------27--------------(AP:24)	
4	(0 0100)(FS:3)(DR:5)(UM:6)(AC:13) (AP:24)	. . . . . Surveillance, Altitude
5	(0 0101)(FS:3)(DR:5)(UM:6)(ID:13) (AP:24)	. . . . . Surveillance, Identity
6	(0 0110)---------------27--------------(AP:24)	
7	(0 0111)---------------27--------------(AP:24)	
8	(0 1000)---------------27--------------(AP:24)	
9	(0 1001)---------------27--------------(AP:24)	
10	(0 1010)---------------27--------------(AP:24)	
11	(0 1011)(CA:3)(AA:24) (PI:24)	. . . . . All-Call Reply
12	(0 1100)---------------27------------- (AP:24)	
13	(0 1101)---------------27------------- (AP:24)	
14	(0 1110)---------------27------------- (AP:24)	
15	(0 1111)---------------27------------- (AP:24)	
16	(1 0000)(VS:1)-7-(RI:4)--2--(AC:13)(MV:56)(AP:24)	. .Long Special Surveillance
17	(1 0001)---------------83---------------------(AP:24)	
18	(1 0010)---------------83---------------------(AP:24)	
19	(1 0011)---------------83---------------------(AP:24)	
20	(1 0100)(FS:3)(DR:5)(UM:6)(AC:13)(MB:56) (AP:24)	. .Comm-B, Altitude
21	(1 0101)(FS:3)(DR:5)(UM:6)(ID:13)(MB:56) (AP:24)	. .Comm-B, Identity
22	(1 0110)---------------83---------------------(AP:24)	
23	(1 0111)---------------83---------------------(AP:24)	
24	(11)--1--(KE:1)(ND:4)(MD:80) (AP:24)	. .Comm-D (ELM)

Notes: (1) *(XX:M) denotes a field designated "XX" which is assigned M bits.*
(2) *---N--- denotes free coding space with N available bits.*
(3) *For downlink formats (DF) 0 through 23 the format number corresponds to the binary code in the first 5 bits of the reply. Format number 24 is arbitrarily defined as the format beginning with "11" in the first two bit positions while the following three bits may vary with the reply content.*
(4) *All formats are shown for completeness, although a number of them are unused.*

Fig. 3.2-2. Overview of Mode S Reply Formats.

3.2.2.1 Essential Fields.

Each Mode S transmission contains two essential fields: One describing the format and the other a 24-bit field which contains either the address or the interrogator identity overlaid on parity as described in paragraph 4.1. The format descriptor is the field at the beginning of the transmission and the 24-bit field always occurs at the end of the transmission. The formats are described by the UF (Uplink Format) or DF (Downlink Format) descriptors.

3.2.2.2 Mission Fields.

The remaining coding space is used to transmit the mission fields. For specific missions, a specific set of fields is prescribed. Mission fields have two-letter designators within this National Standard.

3.2.2.3 Subfields.

Subfields may appear within mission fields. Subfields are labeled with three-letter designators within this National Standard.

3.3 Field Descriptions.

The fields are described in alphabetical order in the following paragraphs. An index is provided in Table 3.3-1.

3.3.1 AA Address, Announced.

This 24-bit (9-32) downlink field contains the aircraft address in the clear and is used in DF=11, the All-Call reply.

3.3.2 AC Altitude Code.

This 13-bit (20-32) downlink field contains the altitude code and is used in formats DF= 0,4,16 and 20. If the M-bit (26) is zero, the pattern of ref A, 2.7.13.2.5 is used in the remaining bits in the sequence: C1, A1, C2, A2, C4, A4, M, B1, zero, B2, D2, B4, D4. Zero is transmitted in each of the 13 bits if altitude information is not available. If the M-bit (26) is set to "one", metric altitude is contained in this field.

Note 1: Metric altitude codes are not included in this Standard.

Note 2: Bit 28 contains the D1 pulse which is not part of the altitude code; zero is transmitted.

3.3.3 AP Address/Parity.

This 24-bit field (33-56 or 89-112) contains parity overlaid on the address according to 4.1.2. and appears at the end of all transmissions on both uplink and downlink with the exception of format DF=11.

Table 3.3-1. FIELD INDEX

Field	Sub Field	Bits No.	Bits Position	Formats Up	Formats Down	Reference Paragraph(s) Content	Reference Paragraph(s) Protocol
AA		24	9-32		X	3.3.1	5.6.1.1
AC		13	20-32		X	3.3.2	5.6.1.3
AP		24 24	33-56 89-112	X	X	3.3.3	4.1.2, 4.2.1.1, 4.2.1.2
AQ		1	14	X		3.3.4	4.17.1
CA		3	6-8		X	3.3.5	4.6.1
DF		5	1-5		X	3.3.6	
DI		3	14-16	X		3.3.7	
DR		5	9-13		X	3.3.8	4.11.2, 4.12.2.1
FS		3	6-8		X	3.3.9	4.5
ID		13	20-32		X	3.3.10	
II		4	10-13	X		3.3.11	4.13.1.1&2, 4.13.6
KE		1	4		X	3.3.12	4.12.1.3, 4.12.2.2
MA		56	33-88	X		3.3.13	4.10
	ADS	8	33-40	X		3.3.13.1	
MB		56	33-88		X	3.3.14	4.11
	ACS	20	45-64		X	4.6.2.2	
	BCS	16	65-80		X	4.6.2.2	4.6.2.2
	BDS	8	33-40		X	3.3.14.1	4.11.1
	CFS	4	41-44		X	4.6.2.1	
	ECS	8	81-88		X	4.6.2.2	4.6.2.2
	FIS	48	41-88		X	4.14.1	
MC		80	9-88	X		3.3.15	4.12.1
	CDS	8	9-16	X		3.3.15.1	
	SRS	16	9-24	X		4.12.2.2.1	
MD		80	9-88		X	3.3.16	4.12.2
	DDS	8	9-16		X	3.3.16.1	
	TAS	16	17-32		X	4.12.1.3.3	
MU		56	33-88	X		3.3.17	
MV		56	33-88		X	3.3.18	
NC		4	5-8	X		3.3.19	4.12.1
ND		4	5-8		X	3.3.20	4.12.2.2
PC		3	6-8	X		3.3.21	4.3, 4.11, 4.12
PI		24	33-56		X	3.3.22	4.1.2
PR		4	6-9	X		3.3.23	
RC		2	3,4	X		3.3.24	4.12.2, 4.12.2.2
RI		4	14-17		X	3.3.25	4.17.1
RL		1	9	X		3.3.26	4.17.1
RR		5	9-13	X		3.3.27	4.2.2.1, 4.6.2

Table 3.3-1. (Continued)

Field	Sub Field	Bits No.	Bits Position	Formats Up	Formats Down	Reference Paragraph(s) Content	Reference Paragraph(s) Protocol
SD		16	17-32	X		3.3.28	4.8, 4.13.1.1
	IIS	4	17-20	X		4.13.1.1	
	LOS	1	26	X		4.13.1.1	4.13.6.1
	MBS	2	21,22	X		4.13.1.1	4.13.3.2
	MES	3	23-25	X		4.13.1.1	
	RRS	4	21-24	X		4.11.1.1.1	4.11.1.1
	RSS	2	27,28	X		4.13.1.1	
	TMS	4	29-32	X		4.13.1.1	
UF		5	1-5	X		3.3.29	
UM		6	14-19		X	3.3.30	4.7
	IDS	2	18,19		X	4.13.1.2	
	IIS	4	14-17		X	4.13.1.2	
VS		1	6		X	3.3.31	4.5.2

3.3.4 AQ Acquisition, Special.

This 1-bit field (14) designates formats UF=0, 16 as acquisition transmissions and is repeated as received by the transponder in bit 14 of the RI field of DF= 0, 16.

3.3.5 CA Capability.

This 3-bit (6-8) downlink field reports transponder capability and is used in DF-11, the All-Call reply. The codes are:

0 = No extended capability report available
1 = Comm A/B extended capability report available
2 = Comm A/B/C and extended capability report available
3 = Comm A/B/C/D and extended capability report available
4-7 = Not assigned

3.3.6 DF Downlink Format.

In all downlink formats this field is the transmission descriptor and is coded according to Figure 3.2-2. See note (3) at Fig. 3.2-2.

3.3.7 DI Designator, Identification.

This 3-bit (14-16) uplink field identifies the coding contained in the SD field in formats UF=4, 5, 20, 21. The codes are:

0 = SD not used
1 = SD contains multisite information (4.13)
2-6 = Not assigned
7 = SD contains extended data readout request (4.11.1.1)

3.3.8 DR Downlink Request.

This 5-bit (9-13) downlink field is used to request extraction of downlink messages from the transponder by the interrogator and appears in formats DF= 4, 5, 20, 21. The codes are:

0 = No downlink request
1 = Request to send Comm-B message (B bit set)
2-15 = Not assigned
16-31 = (See Comm-D protocol, 4.12.2.1)

Codes 1-15 take precedence over codes 16-31.

3.3.9 FS Flight Status.

This 3-bit (6-8) downlink field reports the flight status of the aircraft and is used in formats DF= 4, 5, 20, 21 as described in 4.5. The codes are:

Code	Alert	SPI	Airborne	On the Ground
0	no	no	yes	no
1	no	no	no	yes
2	yes	no	yes	no
3	yes	no	no	yes
4	yes	yes	either	
5	no	yes	either	
6 and 7	are not assigned			

3.3.10 ID Identification, 4096 code.

This 13-bit (20-32) downlink field in DF = 5,21 contains the "4096" identification code reporting the numbers set by the pilot. The pattern of ref. A, 2.6 is used.

3.3.11 II Interrogator Identification.

This 4-bit (10-13) uplink field identifies the interrogator and appears in UF=11, the Mode S - only All-Call. 4.13.6 describes the coding as used in the multisite lockout protocol.

Note: The same information also may appear in the IIS subfields; see 4.13.1.1 and 4.13.1.2.

3.3.12 KE Control, ELM.

This 1-bit (4) downlink field defines the content of the ND and MD fields in Comm-D replies, DF=24 (see 4.12.1.3.2 and 4.12.2.2). If KE=0, MD is part of an ELM reply; if KE=1, MD contains the acknowledgement for an uplink ELM.

3.3.13 MA Message, Comm-A.

This 56-bit (33-88) uplink field contains messages directed to the aircraft and is part of Comm-A interrogations, UF=20, 21. The field contains the 8-bit Comm-A Definition Subfield ADS.

Note: Message content and codes are not included in this Standard.

3.3.13.1 ADS A-Definition Subfield in MA.

This 8-bit (33-40) uplink subfield defines the content of the MA message field of which it is part. ADS is expressed in two groups of 4 bits each, ADS1 (33-36) and ADS2 (37-40).

3.3.14 MB Message, Comm-B.

This 56-bit (33-88) downlink field contains messages to be transmitted to the interrogator and is part of the Comm-B replies DF=20, 21. The field contains the 8-bit Comm-B Definition Subfield BDS.

Note: Message content and codes are not included in this Standard except in the items described in 4.6.2.1 and 4.14.1.

3.3.14.1 BDS B-Definition Subfield, a subfield in MB.

This 8-bit (33-40) downlink subfield defines the content of the MB message field of which it is part. BDS is expressed in two groups of 4 bits each, BDS1 (33-36) and BDS2 (37-40).

3.3.15 MC Message, Comm-C.

This 80-bit (9-88) uplink field contains one segment of a sequence of segments transmitted to the transponder in the ELM (Extended Length Message) mode. MC is part of UF=24.

Note: Message content and codes are not included in this Standard except for the item 4.12.2.2.1.

3.3.15.1 CDS C-Definition Subfield, a subfield in MC.

This 8-bit (9-16) uplink subfield defines the message to be sent to the transponder and is included in segment zero of an ELM uplink sequence.

Note: CDS is shown here for convenience; the coding of this field is not included in this Standard.

3.3.16 MD Message, Comm-D.

This 80-bit (9-88) downlink field contains one segment of a sequence of segments transmitted by the transponder in the ELM (Extended Length Message) mode. It may also contain a summary of received MC segments of an uplink ELM. MD is part of DF=24.

Note: Message content and codes are not included in this Standard; except for the item in 4.12.1.3.3.

3.3.16.1 DDS D-Definition Subfield, a subfield in MD.

This 8-bit (9-16) downlink subfield defines the message to be transmitted and is included in segment zero of an ELM downlink sequence.

3.3.17 MU Message, Comm U.

This 56-bit (33-88) uplink field contains information used in air-to-air exchanges and is part of the long special surveillance interrogation UF=16. This message field does not use the Comm-A protocol.

Note: Message content and codes are not included in this Standard.

3.3.18 MV Message, Comm-V.

This 56-bit (33-88) downlink field contains information used in air-to-air exchanges and is part of the long special surveillance reply DF=16. This message field does not follow the Comm-B protocol.

Note: Message content and codes are not included in this Standard.

3.3.19 NC Number of C-Segment.

This 4-bit (5-8) uplink field gives the number of a segment transmitted in an uplink ELM and is part of a Comm-C interrogation, UF=24. The protocol is described in 4.12.1

3.3.20 ND Number of D-Segment.

This 4-bit (5-8) downlink field gives the number of a segment transmitted in a downlink ELM and is part of a Comm-D reply, DF=24. The protocol is described in 4.12.2.

3.3.21 PC Protocol.

This 3-bit (6-8) uplink field contains operating commands to the transponder and is part of surveillance and Comm-A interrogations UF=4, 5, 20, 21. The codes are:

0 = No changes in transponder state
1 = Non-Selective All-Call lockout(4.3.1)
2 = Not assigned
3 = Not assigned
4 = Cancel B (4.11.2)
5 = Cancel C (4.12.1.3.4)
6 = Cancel D (4.12.2.3)
7 = Not assigned

3.3.22 PI Parity/Interrogator Identity.

This 24-bit (33-56) downlink field contains the parity overlaid on the interrogator's identity code according to 4.1.2. PI is part of the reply to the Mode S-only All-Call, DF=11.

3.3.23 PR Probability of Reply.

This 4-bit (6-9) uplink field contains commands to the transponder which specify the probability of reply to the Mode S-only All-Call interrogation UF=11 that contains the PR. A command to disregard any lockout state can also be given. The assigned codes are as follows:

0 = Reply with probability = 1
1 = Reply with probability = 1/2
2 = Reply with probability = 1/4
3 = Reply with probability = 1/8
4 = Reply with probability = 1/16
5,6,7 = Do not reply
8 = Disregard lockout, reply with probability = 1
9 = Disregard lockout, reply with probability = 1/2
10 = Disregard lockout, reply with probability = 1/4
11 = Disregard lockout, reply with probability = 1/8
12 = Disregard lockout, reply with probability = 1/16
13,14,15 = Do not reply

Note: On receipt of a Mode S-only All-Call containing a PR code other than 0 or 8, the transponder executes a random process and makes a reply decision for this interrogation in accordance with the commanded probability. The random occurrence of replies enables the interrogator to acquire closely spaced aircraft whose replies would otherwise synchronously garble each other.

3.3.24 RC Reply Control.

This 2-bit (3,4) uplink field designates the transmitted segment as initial, intermediate or final if valued at 0,1,2 respectively. RC=3 is used to request Comm-D downlink action by the transponder. RC is part of the Comm-C interrogation, UF=24. The protocols are described in 4.12.1 and 4.12.2.2.

3.3.25 RI, Reply Information Air-to-Air.

This 4-bit (14-17) downlink field appears in the special surveillance replies DF=0,16 and reports airspeed capability and type of reply to the interrogating aircraft. The coding is as follows:

0-7 = Codes indicate that this is the reply to an air-to-air non-acquisition interrogation. Other details will be assigned in the TCAS standard.
8-15 = Codes indicate that this is an acquisition reply

8 = No maximum airspeed data available
9 = Airspeed is up to 75 knots
10 = Airspeed is between 75 and 150 knots
11 = Airspeed is between 150 and 300 knots
12 = Airspeed is between 300 and 600 knots
13 = Airspeed is between 600 and 1200 knots
14 = Airspeed is more than 1200 knots.
15 = Not assigned

Bit 14 of this field replicates the AQ bit (3.3.4) of the interrogation resulting in the coding scheme above.

3.3.26 RL Reply Length.

This 1-bit (9) uplink field in UF=0,16 commands a reply in DF=0 if set to "0" and a reply in DF=16 if set to "1".

3.3.27 RR Reply Request.

This 5-bit (9-13) uplink field contains length and content of the reply requested by the interrogators. RR is part of the surveillance and Comm-A interrogations UF=4, 5, 20, 21. The codes are outlined in the table below:

RR Code	Reply Length	MB Content
0-15	Short	------
16	Long	Air initiated Comm-B (4.11.2)
17	Long	Extended Capability (4.6.2)
18	Long	Flight ID (4.14)
19-31	Long	Not assigned

Note 1: If the first bit of the RR code is a one, the last four bits of the 5-bit RR code, if transformed into their decimal equivalent, designate the number (BDS1) of the requested source. BDS2 is assumed to be zero if not specified (by DI=7 and RRS).

Note 2: Data Link message codes are not included in this Standard.

3.3.28 SD Special Designator.

This 16-bit (17-32) uplink field can contain control codes affecting transponder protocol and is part of surveillance and Comm-A interrogations UF=4, 5, 20, 21. The content of this field is specified by the DI field.

3.3.28.1 IIS, Subfield in SD.

This 4-bit subfield (17-20) appears in all SD fields of uplink formats 4, 5, 20 and 21 regardless of the DI (3.3.7, 4.13) code. IIS is the Interrogator Identifier: 4.13.1.1.

3.3.29 UF Uplink Format.

The first field in all uplink formats is the transmission descriptor and is coded according to Figure 3.2-1.

3.3.30 UM Utility Message

This 6-bit (14-19) downlink field in DF= 4, 5, 20, 21 contains control and status information. See 4.13.1.2, 4.13.3.1.1 and 4.13.5.1.1.

3.3.31 VS Vertical Status.

This 1-bit (6) downlink field in DF=0, 16 indicates, when set to zero that the aircraft is airborne and indicates, if set to "one" that the aircraft is on the ground.

3.3.32 Free and Unassigned Coding Space.

Free coding space as indicated in Figures 3.2-1 and 3.2-2 contains all zeroes as transmitted by interrogators and transponders. Non-assigned coding space within existing fields is reserved for possible future use; see 1.3.1.

3.3.33 Future Coding.

Because yet unassigned free coding space is transmitted as zeroes, future coding must define a zero block as a default code, i.e., no message is sent, no command given, no capability exists if a future new field contains all zeroes.

4. PROTOCOL.

Note: This section describes the interactions between the sensor (interrogator) and the transponder required for the proper functioning of the Mode S surveillance and data link tasks. Data interchanged on the Mode S link may have their own sub-protocols; these are not part of this Standard.

4.1 Error Protection.

4.1.1 Technique.

Parity check coding is used within Mode S interrogations and replies to provide protection against the occurrence of errors.

Note: A circuit suitable for implementing the technique is shown in Fig. 4.1-1.

4.1.1.1 Parity Check Sequence.

A sequence of 24 parity check bits is generated by a code described in 4.1.1.2 and is incorporated into the field formed by the last 24 bits of all Mode S transmissions. The 24 parity check bits are combined with either the address or the interrogator identification as described in 4.1.2. The resulting combination then forms either the AP (Address/Parity) or the PI (Parity/Identification) fields.

4.1.1.2 Parity Check Sequence Generation.

The sequence of 24 parity bits (p_1, p_2, ... p_{24}) is generated from the sequence of information bits (m_1, m_2, ... m_k) where k is 32 or 88 for short or long transmissions respectively. This is done by means of a code that is generated by the polynomial:

$$G(x) = \sum_{i=0}^{24} g_i x^i$$

where g_i = 1 for i = 0, 3, 10, and 12 through 24
0 otherwise

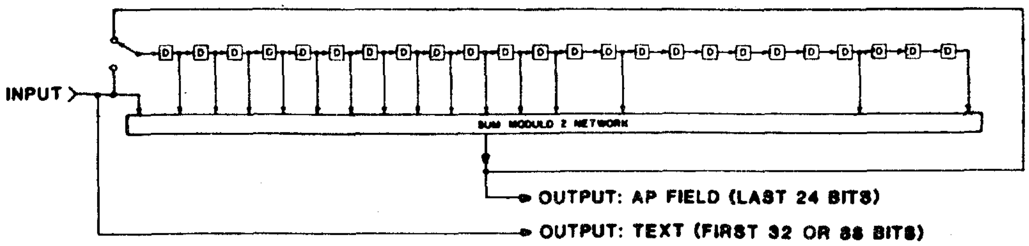
When by the application of binary polynomial algebra the above G(x) is divided into $[M(x)]x^{24}$ where the information sequence M(x) is expressed as:

$$M(x) = m_k + m_{k-1}x + m_{k-2}x^2 + \ldots + m_1 x^{k-1}$$

the result is a quotient and a remainder R(x) of degree < 24. The bit sequence formed by this remainder represents the parity check sequence. Parity bit p_i, for any i from 1 to 24, is the coefficient of x^{24-i} in R(x).

Note: The effect of multiplying M(x) by x^{24} is to append 24 zero bits to the end of the sequence.

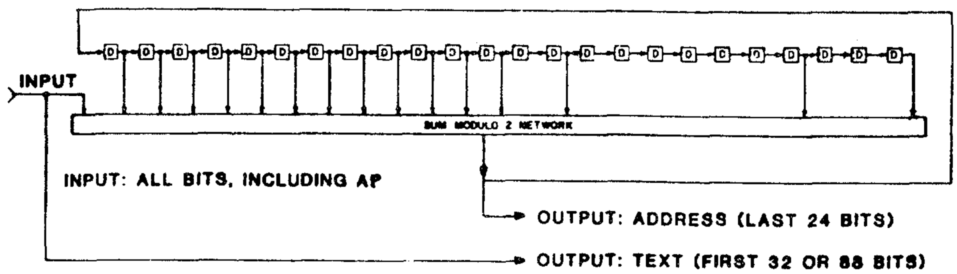
SENSOR ENCODER



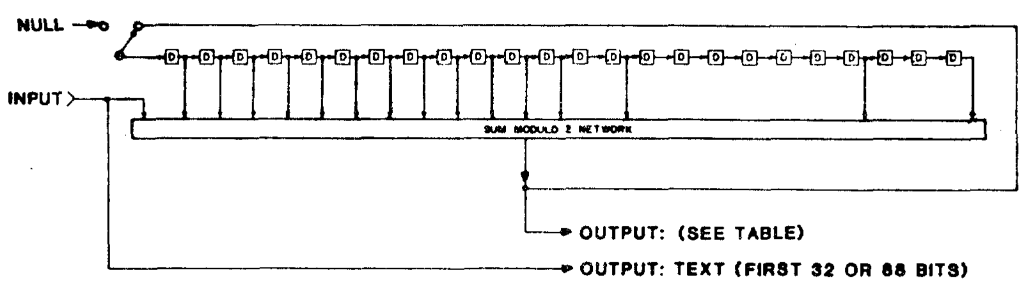
INPUT: ALL BITS, INCLUDING ADDRESS

SWITCH: UP EXCEPT FOR LAST 24 BITS

TRANSPONDER DECODER



TRANSPONDER ENCODER AND SENSOR DECODER



	TRANSPONDER	SENSOR
INPUT	ALL BITS, INCLUDING ADDRESS	ALL BITS INCLUDING AP FIELD
OUTPUT	AP FIELD = LAST 24 BITS	ADDRESS = LAST 24 BITS
SWITCH	RIGHT EXCEPT FOR LAST 24 BITS	

—[D]—
1 BIT INTERVAL DELAY

FOR ALL CODERS: NULLS IN D AT START OF PROCESS

Fig. 4.1-1. Functional Diagram of Mode S Sensor and Transponder Encoders.

4.1.2 AP or PI Field Generation.

The address used for AP field generation is either the discrete address (4.2.1.1) or the all-call address (4.2.1.2). The address is formed by a sequence of 24 bits, (a_1, a_2 ... a_{24}). In the discrete address, a_1 is the bit transmitted first in the AA field of an All-Call reply. This address sequence is used in the downlink Address/Parity field generation, while a modified form of this sequence (b_1, b_2 ... b_{24}) is required for uplink Address/Parity field generation.

The interrogator identifier used for PI field generation is formed by a sequence of 24 bits, (a_1, a_2, ... a_{24}) where the first 20 bits have zero value and the last four bits are a replica of the II field.

Bit b_i is the coefficient of x^{i-1} in the polynomial H(x)A(x), where

$$A(x) = a_1 + a_2x + a_3x^2 + \ldots + a_{24}x^{23}$$

and

$$H(x) = \sum_{i=0}^{24} g_i x^{24-i}$$

The sequence of bits transmitted in the Address/Parity field is:

$$t_{k+1},\ t_{k+2} \cdots t_{k+24}.$$

Note: The bits are numbered in order of transmission, starting with k+1.

4.1.2.1 Uplink Field.

In uplink transmissions:

$$t_{k+i} = b_i \oplus p_i$$

where "$\oplus$" prescribes modulo-2 addition; i = 1 is the first bit transmitted in the AP field.

4.1.2.2 Downlink Field.

In downlink transmissions:

$$t_{k+i} = a_i \oplus p_i$$

where "$\oplus$" prescribes modulo-2 addition; i=1 is the first bit transmitted in the AP or PI field.

4.2 Interrogation-Reply Protocol.

Note: Mode S is based on the principle of directed interrogations. Interaction between the interrogator and the transponder occurs only if the transponder is correctly addressed.

4.2.1 Interrogation Acceptance.

ATCRBS interrogations are accepted only if:

1. The transponder is not in suppression (4.2.2.4.2)
2. The transponder is not in a Mode S transaction cycle.

Mode S Interrogations are accepted only if:

1. The address of the recipient is as defined in 4.2.1.1. and 4.2.1.2
2. Parity (4.1) is established
3. No lockout condition (4.3.1 or 4.13.6) applies.
4. The transponder is not in a transaction cycle.
5. There is no data overflow (5.6.2.3.1)

The transaction cycle begins when the transponder has recognized an interrogation type and ends when the transponder has finished the reply or has aborted processing of this interrogation.

Note: A Mode S interrogation is recognized when the sync phase reversal has been detected. The transaction cycle ends when either the interrogation has been accepted and has been replied to or when the interrogation has not been accepted because of wrong address, lockout, etc.

An ATCRBS interrogation is recognized when a proper P1 - P3 interval has been detected and a following leading edge of a P4 has not been detected.

During ATCRBS suppression intervals recognition of P1 -P2 - P3 intervals is suspended.

In the interval between P1 and an expected P3 a transponder is not in a transaction cycle.

4.2.1.1 Discrete Address.

Each transponder is assigned a unique address. If the address so assigned is identical to the address extracted from the received interrogation according to 4.1.2 and 4.1.2.1, the interrogation is accepted and the content is evaluated and acted upon according to protocols described elsewhere in this Standard.

4.2.1.2 All-Call Address.

If the address extracted from the received interrogation consists of 24 binary "ones", the response of the transponder to such an interrogation depends on the content of the transmission. If UF=11, the transmission is a Mode S-only All-Call (4.2.1.3) and will be accepted subject to 4.2.2.4.4. If UF>15, the transmission is designated a "broadcast" (4.15) and will be accepted.

4.2.1.3 Mode S-only All-Call.

On receipt of the Mode S-only All-Call, UF=11, the decoding process of 4.1.2 and 4.1.2.1 results in an address consisting of 24 binary ones. This is the universal All-Call address and this interrogation is accepted according to the PR code (3.3.23) unless the lockout protocol of 4.3.1 or 4.13.6 is in effect.

4.2.1.4 ATCRBS/Mode S All-Call.

An ATCRBS/Mode S All-Call interrogation (2.3.2, 1.6-microsecond P_4) is accepted unless either the lockout protocol of 4.3.1 or suppression (4.2.2.4.2) are in effect.

Receipt of an ATCRBS/Mode S All-Call interrogation also has the same effect as reception of the uplink format UF=11 with a unity probability-of-reply command.

4.2.1.5 ATCRBS-only All-Call.

A Mode S transponder does not accept the ATCRBS-only All-Call (2.3.2, 0.8-microseconds P_4).

4.2.2 Interrogation - Reply Coordination.

The reply format required on acceptance (4.2.1) of an interrogation is the format denoted by the DF code, which is numerically equal to the UF code of the interrogation, with the exceptions described in the following paragraphs.

4.2.2.1 Reply to Air-to-Air Interrogations, UF's 0,16.

The reply format required for these interrogations follows the RL code of 3.3.26.

4.2.2.2 Replies to Surveillance and Comm-A Interrogations, UF's 4,5,20,21.

The reply format required for these interrogations is determined by the code within the RR field, according to the following table:

Uplink Format, UF	RR Code	Downlink Format, DF
4	0 through 15	4
5	0 through 15	5
20	0 through 15	4
21	0 through 15	5
4	16 through 31	20
5	16 through 31	21
20	16 through 31	20
21	16 through 31	21

Note: In effect, the first bit of the RR field determines the length of the required reply.

4.2.2.3 Interrogation and Reply Formats UF=DF=24

This set of interrogation and reply formats forms the ELM system. Interrogation-reply coordination for these formats is described in (4.12).

4.2.2.4 No Reply.

Note: Other no-reply conditions are described in 4.12.1.

4.2.2.4.1 Broadcast.

If an interrogation has been accepted with an All-Call address, but with UF≠11 (4.2.1.2), no reply is transmitted.

4.2.2.4.2 Suppression.

Suppression as described in ref. A, paragraph 2.7.4 applies to responses to ATCRBS, ATCRBS/Mode S All-Calls and ATCRBS-only All-Call interrogations. ATCRBS and ATCRBS/Mode S All-Calls are not accepted if the P_1 pulse is received during the suppression period.

4.2.2.4.3 Formats for which Transponder is not Equipped.

On receipt (4.2.1) of an interrogation format for which a transponder does not have the required reply capability, the interrogation will not be accepted.

4.2.2.4.4 Stochastic All-Calls.

A Mode S-only All-Call with PR codes other than 0 or 8 may not be accepted depending upon the outcome of the random process (3.3.23) executed by the transponder.

4.2.3 Reply Delay and Jitter.

Note: After an interrogation has been accepted and if a reply is required, this reply transmission begins after a fixed delay needed to carry out the protocols. Different values for this delay are assigned for ATCRBS, Mode S, and ATCRBS/ Mode S All-Call replies.

4.2.3.1 Reply Delay and Jitter for ATCRBS.

The reply delay and jitter for ATCRBS transactions is as prescribed in reference A, 2.7.11.

4.2.3.2 Reply Delay and Jitter for Mode S.

For all signal levels between the minimum trigger level (MTL) and -21 dBm the leading edge of the first preamble pulse of the reply (2.3.5.2.1) occurs 128 ±0.25 microseconds after the sync phase reversal (2.3.3.2) of the received P6. The jitter of the reply delay does not exceed 0.05 microseconds, rms.

4.2.3.3 Reply Delay and Jitter for ATCRBS/Mode S All-Call.

For all signal levels between 3 dB above MTL and -21 dBm, the leading edge of the first preamble pulse of the reply (2.3.5.2.1) occurs 128 ±0.5 microseconds after the leading edge of the P4 pulse of the interrogation (2.3.2) and the jitter does not exceed 0.06 microseconds, rms.

Note: A jitter of 0.06 microseconds, rms, is consistent with the jitter prescribed in ref. A, 2.7.11.

4.3 Lockout Protocol.

Note: Transponders can be prevented from accepting certain interrogations by command from an interrogator.

4.3.1 Non-Selective All-Call Lockout.

On acceptance of an interrogation containing code 1 in the PC field , a transponder commences to reject (= not accept) two types of All-Call interrogations: a) UF=11 with II=0 and b) the ATCRBS/Mode S All-Call of 2.3.2. This lockout condition persists for T_D seconds after the last receipt of the command but can be overridden by the PR codes 8 through 12.

Note 1: The value of T_D is given in 5.4.6.

Note 2: Multisite All-Call lockout is described in 4.13.6.

4.4 Squitter Protocol.

Note: Mode S Transponders transmit squitters (unsolicited replies) to facilitate acquisition by collision avoidance systems.

4.4.1 Squitter Format.

The format used for squitter transmissions is the All-Call reply, DF=11, using an interrogator identifier of zero (4.16).

4.4.2 Squitter Rate.

Squitter transmissions are emitted at random intervals that are uniformly distributed over the range from 0.8 to 1.2 seconds, with the following exceptions:

a. The scheduled squitter is delayed if a reply is required in response to an interrogation.

b. The scheduled squitter is delayed if a mutual suppression interface is active (see note below).

A squitter cannot be interrupted by link transactions or mutual suppression activity after the squitter transmission has begun.

Note: A mutual suppression system may be used to connect on-board equipment operating in the same frequency band in order to prevent mutual interference. Squitter action resumes as soon as practical after a mutual suppression interval.

4.4.3 Squitter Antenna Selection.

Diversity transponders transmit squitters alternately from the two antennas.

4.5 Flight Status Protocol.

Note: Mode S equipped aircraft report details of their flight status in the FS field of DF's 4, 5, 20 and 21 and in the VS field of DF's 0 and 16. The source of and the rules for such reports follow.

4.5.1 Alert.

The 4096 identification code transmitted in ATCRBS replies and in downlinks DF 5 and DF 21 can be changed by the pilot. When such a change is made, an alert condition is established which may be temporary or permanent.

4.5.1.1 Permanent Alert Condition.

If the identification code is changed to 7700, 7600 or 7500, the alert condition is permanent.

4.5.1.2 Temporary Alert Condition.

If the identity code is changed to a value other than those listed in 4.5.1.1, the alert condition is temporary and is self cancelling after T_C seconds.

Note: The value of T_C is given in 5.4.6.

4.5.1.3 Reporting of Alert Condition.

The Alert condition is reported in the FS field: 3.3.9.

4.5.1.4 Termination of the Alert Condition.

The permanent Alert condition is terminated and replaced by a temporary Alert condition when the identification code is set to a value other than 7700, 7600 or 7500.

4.5.2 Ground Report.

The Mode S transponder has a means for reporting that the aircraft is on the ground. This information is coded in the FS and VS fields.

4.5.3 Special Position Identification.

When manually selected, an equivalent of the ATCRBS special position identification (SPI) pulse is transmitted by Mode S transponders in the FS field of surveillance and Comm-B replies, DF= 4,5,20,21. This code is transmitted for T_I seconds after initiation and can be reinitiated at any time. See ref. A: 2.6.3 and ref. A: 2.7.14.

Note: The value of T_I is given in 5.4.6.

4.6 Capability Reporting.

Note: A Mode S installation in an aircraft may be capable of handling a number of data link services. Aircraft capability is reported in special fields.

4.6.1 Capability Report.

The three-bit CA (capability) field, contained in the All-Call reply, DF=11, reports the basic capability of the airborne Mode S installation (see 3.3.5).

4.6.2 Extended Capability Report.

The extended capability report provides the interrogator with a description of the data link capability of the Mode S installation. The report is obtained by a Ground Initiated Comm-B, containing RR=17 (4.11.1).

4.6.2.1 Subfields in MB for Extended Capability Report.

The subfields within the MB field of all extended capability reports are:

BDS1 Code "1" is assigned to this 4-bit (33-36) subfield for all extended capability reports.

BDS2 BDS2 is a 4-bit (37-40) subfield; the basic report uses BDS2=0. More complex Mode S installations report their additional capabilities in various formats assigned to BDS2 codes other than zero.

CFS This 4-bit (41-44) Continuation Subfield contains the BDS2 value of the next additional capability report available from this installation.

4.6.2.2 Coding of the Extended Capability Report.

BDS1: 1 = Extended Capability Report

BDS2: 0 = Basic Report
1 = Additional Report
2-15 = not assigned

CFS: see 4.6.2.1

For BDS2 = 0,1 the extended capability field contains the following subfields:

ACS: This 20 bit (45-64) Comm-A Capability Subfield reports the data link service(s) supported by this installation. If all bits are zero, no Comm-A data link services are supported.

BCS: This 16-bit (65-80) Comm-B Capability Subfield reports the installed data sources that can be accessed by the ground for transmission via a ground initiated Comm-B. If all bits are zero, no data is accessable by a ground initiated Comm-B.

For BDS2 = 0 only:
Bit 65: Flight Identification Report Available

ECS: This 8 bit (81-88) Extended Capability Subfield reports the ELM capability of the installation. If all bits are zero, no ELM data link services are supported.

4.6.2.3 Updating of the Extended Capability Report.

At intervals not exceeding four seconds the transponder compares the current extended capability status with that last reported and if a difference is noted initiates a revised Extended Capability Report by air-initiated Comm-B for BDS1=1 and BDS2=value as required.

4.7 Utility Message Protocol.

Control or status information is transmitted in this downlink field according to 4.13.1.2, 4.13.2.2, 4.13.3.1.1 and 4.13.5.1.1.

4.7.1 Requested Information.

Information to appear in the subsequent reply is requested by the interrogator by coding the SD field within surveillance or Comm-A interrogations, UF=4,5,20,21.

4.7.2 Voluntary Information.

Voluntary information may be sent any time that the UM content is not specified; see 4.13.3.1.1, 4.13.5.1.1.

4.8 Special Designator Protocol.

Note: The 16 bit SD field in UF=4,5,20,21 can be used to transmit control codes.

4.8.1 SD Field Content.

Codes appearing in the SD field are identified by the code in the DI field.

4.8.2 SD Field Coding.

Note: Specific coding details of assigned functions appearing in the SD field are given in 4.11.1.1.1 and 4.13.1.1.

4.9 Data Transactions.

Note: Data exchanges are always under control of the interrogator. Ground-Initiated Comm-A messages are sent directly to the transponder. Ground initiated Comm-B replies are extracted from the transponder by suitable interrogation content. Air-initiated Comm-B messages are announced by the transponder and are transmitted in a subsequent reply only after authorization by the interrogator. Longer messages, either on the uplink or the downlink can be exchanged by the Extended Length Message (ELM) protocol using Comm-C and Comm-D formats. The ELM protocol provides for the transmission of up to sixteen 112-bit message segments before requiring a reply from the transponder. It also allows a corresponding procedure on the downlink. In some areas of overlapping interrogator coverage there is no means for coordinating interrogator activities via direct communication. However, the Comm-B and ELM communication protocols require more than one transaction for completion. Thus coordination is necessary to assure that Comm-B and ELM transactions are not inadvertently closed out by the wrong interrogator. The multisite protocol is used for this coordination in areas where no other means are available.

Air-Initiated Comm-B messages are announced to all interrogators and can be extracted by any interrogator. However, an individual interrogator can use the multisite protocol to reserve for itself the ability to cancel the Comm-B transaction. A similar coordination technique applies to the ELM protocol. A transponder can be instructed to identify the interrogator that has reserved the transponder for an ELM transaction. Only that interrogator can terminate the ELM transaction.

4.10 Comm-A Protocol.

Note: Long uplink messages are contained in the MA field of Comm-A interrogations, UF=20, 21.

4.10.1 A-Acknowledgment.

Receipt of a message in the MA field is automatically acknowledged by the transponder when the reply to this interrogation is transmitted. In case of uplink failure no reply is transmitted and the interrogator sends the message again. In case of downlink failure, a message may be transmitted to the transponder more than once.

4.10.2 Pilot's Acknowledgment.

Note: If an acknowledgment by the pilot of receipt of a message or command is required, a request to this effect and a code for the positive or negative reply must be part of the internal coding of a message field. Pilot operated acknowledgment actuators need not be part of the transponder.

4.10.3 Linked Comm-A Coding.

Peripherals attached to a transponder may use the Linked Comm-A Protocol. The transponder is transparent to this; coding appears in the SD field and is described in 4.13.1.1.

4.11 Comm-B Protocol.

Note: Long downlink messages are contained in the MB field of DF=20, 21. Information transfer by this field can be ground-or air-initiated. The Comm-B protocol governs the required sequence of events.

4.11.1 Ground Initiated Comm-B.

The interrogator can request data to be read out from any one of up to 15 different sources identified by BDS1 codes. Such readout is initiated by transmitting the appropriate one of the codes 17 through 31 in the RR field of a surveillance or Comm-A interrogation, UF=4,5,20,21. On receipt of such request, the reply is transmitted containing the data corresponding to the RR code.

4.11.1.1 Extended Data Readout.

The interrogator can request data to be read out from a source more specifically defined by both BDS1 and BDS2. Such readout is initiated by transmitting DI=7 and in addition to the BDS1 code (as in 4.11.1), the BDS2 code in the SD field.

4.11.1.1.1 RRS Reply Request Subfield in SD.

This 4-bit (21-24) uplink subfield in SD gives the BDS2 code of a requested Comm-B reply if DI = 7 in the same interrogation.

4.11.2 Air Initiated Comm-B.

An air initiated Comm-B sequence starts with the insertion of code 1 in the DR field of a surveillance or Comm-B reply, DF=4,5,20,21. On receipt of this announcement the interrogator transmits code 16 in the RR field of a subsequent interrogation. Receipt of this code by the transponder constitutes the authorization to transmit the data. The resulting MB field contains a BDS code identifying the content of the field. This reply, and others following it, continue to contain code 1 in the DR field. After the message has been transmitted at least once and after code 4 (cancellation) is received in the PC field of UF = 4,5,20,21, the transaction is cancelled and the DR code belonging to this message is immediately removed. Another message waiting to be transmitted can then set DR code 1 so that the reply can contain the announcement of this next message.

If RR=16 is received while no message is waiting to be transmitted, the reply contains all zeroes in the MB field.

Note 1: This protocol assures transmission and receipt of the message in case of link failure, either up or down.

Note 2: Interrogations received with DI=1 may require compliance with the multisite protocol (4.13).

Note 3: Air initiated Comm-B transmissions can be directed to a specific interrogator in a multisite situation. See 4.13.3.1.1.

4.12 ELM Protocol.

Note: The extended length message protocol provides for efficient transmission of long messages by permitting the grouping of up to 16 message segments into a single entity which can be acknowledged by a single reply. Uplink segments are called Comm-C and use UF=24 while downlink segments are called Comm-D and use DF=24.

The multisite protocol (4.13) can be used with the ELM system.

4.12.1 Uplink ELM Protocol.

Uplink extended length messages are transmitted in segments, each segment formed by a Comm-C format.

In addition to the segment content in MC, two protocol fields, NC and RC are used. NC is the number of the segment transmitted. RC identifies the transmission as initial, intermediate or final.

The minimum length of an uplink ELM is two segments. The transfer of all segments may take place without intervening replies. The minimum time between the beginning of successive Comm-C transmissions is 50 microseconds.

4.12.1.1 Initializing Segment Transfer.

The ELM transaction for an n-segment message (NC's 0 through n-1) is initiated by a Comm-C transmission containing RC=0. The text transmitted in MC is stored. The text is the last segment of the message and carries NC = n-1. NC then establishes the number of further segments to be received and to be stored. Receipt of an initializing (RC=0) segment establishes the "setup" in the transponder which is now prepared to accept further segments.

Receipt of another initializing segment results in a new setup within the transponder and causes any previously stored segments to be discarded.

No reply is generated on receipt of an initializing segment.

4.12.1.2 Intermediate Segment Transfer.

Intermediate segments are characterized by RC=1 and are accepted and stored only if the setup of the previous paragraph is in effect and if the received NC is smaller than the value stored at receipt of the initializing segment.

No reply is generated on receipt of an intermediate segment.

Note: Intermediate segments may be transmitted in any order.

4.12.1.3 Final Segment Transfer.

The final segment is characterized by RC=2, will be accepted under all circumstances and requires a reply. The segment content will be stored.

4.12.1.3.1 Completed Message.

The message is completed if all segments announced by NC in the initializing segment have been received. If the message is completed, the message content is delivered to the ELM interface of 5.6.2.2.3, and the setup is deactivated.

4.12.1.3.2 Acknowledgment Reply.

The acknowledgment reply to a final segment is a Comm-D transmission, with KE=1. KE=1 indicates that the MD field contains the subfield TAS that reports which segments have been received.

The information contained in the TAS subfield is continually updated while segments are received and is not cleared until a new initializing segment is received or until closeout (4.12.1.3.4).

Note: Segments lost in uplink transmission are noted by their absence in the TAS report and are retransmitted by the interrogator which will then send further final segments to assess the situation.

4.12.1.3.3 TAS Transmission Acknowledgement Subfield in MD.

This 16-bit (17-32) downlink subfield in MD reports the segments received so far in a Comm-C sequence. Starting with bit 17, which denotes segment number zero, each of the following bits is set to one if the corresponding segment of the sequence has been received. TAS appears in MD if KE=1 in the same reply.

4.12.1.3.4 Closeout.

A closeout transmission informs the transponder that the TAS has been received and that it should be cleared. This cancellation, PC=5, is contained in a surveillance or Comm-A interrogation, UF=4, 5, 20, 21.

An uncompleted message, present when the closeout is received, will be cancelled.

4.12.2 Downlink ELM Protocol.

Downlink extended length messages are transmitted only after authorization by the interrogator. The segments to be transmitted are contained in Comm-D replies.

Note: Comm-D transmissions can be directed to a specific interrogator, see 4.13.5.1.1.

4.12.2.1 Initialization.

To request permission to send n segments, the transponder inserts the code corresponding to the value 15+n into the DR field of a surveillance or Comm-B reply, DF=4,5,20,21.

4.12.2.2 Authorization and Transmission.

The interrogator requests the transmission of Comm-D segments by a Comm-C interrogation characterized by RC=3. This Comm-C format carries the SRS subfield which is a summary of the segments to be transmitted. On receipt of this authorization the transponder transmits the segments at a rate of one every 136 ±1 microseconds by means of Comm-D formats with KE=0 and ND corresponding to the number of the segment in MD. Segments can be transmitted in any order.

The authorization process may be repeated by the interrogator.

4.12.2.2.1 SRS Segment Request Subfield in MC.

If a Comm-C interrogation (UF=24) contains RC=3 it also contains a list of segment request-authorizations in the 16-bit (9-24) SRS subfield. Starting with bit 9, which denotes the first segment, each of the following bits is set to one if the transmission of the corresponding segment is requested.

4.12.2.3 Closeout.

A closeout transmission is used to inform the transponder that all segments have been received and that the DR field should be reset. This cancellation, PC=6, is contained in a surveillance or Comm-A interrogation.

4.13 Multisite Protocols.

Note: Under certain circumstances it may be necessary for several Mode S interrogators which have overlapping coverage to operate without being in direct communication with each other. When this occurs, conflicting or overlapping requests to the transponder must be avoided. The multisite protocols described in this section provide a means to prevent such conflicts. In any defined airspace all message transfer protocols (air initiated Comm-B and ELM) are used either all with or all without the multisite protocol.

4.13.1 Multisite Data Formats.

4.13.1.1 Subfields in SD.

The SD field contains information as follows:

a) Regardless of the DI code:

IIS, the 4-bit (17-20) Interrogator Identifier Subfield contains the self-identification code of the interrogator which is numerically identical to the II code transmitted by the same interrogator in the Mode S-only All-Call. IIS codes are assigned to interrogators and range from 0 through 15; IIS code zero is not a valid interrogator identifier for multisite purposes.

b) If the DI code = 1:

MBS, the 2-bit (21,22) Multisite Comm-B subfield has been assigned the following codes:

0 = No Comm-B action
1 = Comm-B reservation
2 = Comm-B closeout

MES, the 3-bit (23-25) Multisite ELM subfield contains reservation and closeout commands for ELM as follows:

0 = No ELM action
1 = Comm-C reservation
2 = Comm-C closeout
3 = Comm-D reservation
4 = Comm-D closeout
5 = Comm-C reservation and Comm-D closeout
6 = Comm-C closeout and Comm-D reservation
7 = Comm-C and Comm-D closeouts

RSS, the 2-bit (27,28) Reservation Status Subfield can request the transponder to report its reservation status in the UM field. The following codes have been assigned:

0 = No request
1 = Report Comm-B reservation status in UM
2 = Report Comm-C reservation status in UM
3 = Report Comm-D reservation status in UM

c) If the DI code is 1 or 7:

LOS, the 1-bit (26) Lockout Subfield, if set to "1" initiates a multisite All-Call lockout to Mode S-only All-Calls (UF=11) from the interrogator indicated in IIS of the same interrogation. If LOS is set to "0", no change in lockout state is commanded.

TMS, Tactical Message Subfield, Subfield in SD 4 bits, 29 through 32.

Coding:
0 = No action
1 = Unlinked, priority
2 = Unlinked, acknowledge
3 = Unlinked, priority, acknowledge
4 = Linked 1st segment, single ADS
5 = Linked 1st segment, single ADS priority
6 = Linked 1st segment, single ADS acknowledge
7 = Linked 1st segment, single ADS priority, acknowledge
8 = Linked 1st segment, multiple ADS
9 = Linked 1st segment, multiple ADS, priority
10 = Linked 1st segment, multiple ADS, acknowledge
11 = Linked 1st segment, multiple ADS, priority, acknowledge
12 = Second segment
13 = Third segment
14 = Final segment
15 = Not assigned

Note: *Structure of SD if DI=1*

Position	*# of Bits*	*Subfield*
17-20	*4*	*IIS*
21-22	*2*	*MBS*
23-25	*3*	*MES*
26	*1*	*LOS*
27-28	*2*	*RSS*
29-32	*4*	*TMS*

Note: *Structure of SD if DI=7*

Position	*Number of bits*	*Subfield*
17-20	*4*	*IIS*
21-24	*4*	*RRS**
25	*1*	*Not assigned*
26	*1*	*LOS*
27-28	*2*	*Not assigned*
29-32	*4*	*TMS*

**for RRS see 4.11.1.1.1.*

4.13.1.2 Subfields in UM for Multisite Protocols.

If a surveillance or Comm-A interrogation (UF=4, 5, 20, 21) contains DI=1 and RSS other than zero, the following subfields will be inserted into the reply by the transponder:

IIS, the 4-bit (14-17) Interrogator Identifier Subfield reports the identity of the interrogator that has made a multisite reservation.

IDS, the 2-bit (18-19) Identifier Designator Subfield reports the type of reservation made by the interrogator identified in IIS. Assigned coding is:

0 = no information available
1 = Comm-B reservation active
2 = Comm-C reservation active
3 = Comm-D reservation active

Note: *Structure of UM if DI=1 and RSS ≠ 0*

Position	*# of Bits*	*Subfield*
14-17	*4*	*IIS*
18-19	*2*	*IDS*

4.13.2 Multisite Common Protocols.

The timers and the Interrogator Identity report are common to all multisite message protocols.

4.13.2.1 Multisite Timers.

The multisite protocols require three timers in the transponder:

B-timer
C-timer
D-Timer

Each timer runs for T_R seconds after starting or restarting and is used for automatic closeout of the respective message type. Each timer can be reset (stopped) on command from the ground.

Note: The value of T_R is given in 5.4.6.

4.13.2.2 Interrogator Identity Report.

Transponders insert the interrogator identifier into the UM field of the reply according to the coding of RSS. (4.13.1.1, 4.13.1.2).

4.13.3 Multisite Comm-B Protocol.

Note: The multisite Comm-B protocol augments the standard Comm-B protocol and when not in use does not modify in any way the process described in 4.11.2.

4.13.3.1 Multisite Comm-B Reservation.

When the multisite protocol is in use, an interrogator extracts an air initiated Comm-B by transmitting a surveillance or Comm-A interrogation containing:

RR = 16 (read air initiated Comm-B)
DI = 1 (multisite SD format)
IIS = Interrogator's site number
MBS = 1 (Comm-B reservation request)
RSS = 1 (Comm-B reservation status request)

Note: A multisite Comm-B reservation is invalid and will not be accepted by the transponder unless RR=16; i.e. the announced message is extracted with the same interrogation that made the reservation.

Protocol procedure in response to this interrogation depends upon the state of the B-timer:

B-timer not running:

Store IIS for Comm-B
Start B-timer

B-timer running and interrogator's IIS equals stored Comm-B IIS:

Restart B-timer

B-timer running and interrogator's IIS does not equal stored Comm-B IIS

No change to stored IIS or B-timer

Note: When an interrogator asks for Comm-B reservation status and receives its own site number in the UM of the reply to a multisite Comm-B interrogation, it knows that it is the reserved site for this message and that it should complete the transaction by closing out the message. Other interrogators discontinue processing of this message.

4.13.3.1.1 Multisite Directed Comm-B Transmissions.

If the airborne data system needs to direct a Comm-B message to a specific interrogator, the air-initiated Comm-B protocol (4.11.2) can be used together with the multisite protocol (4.13.3.1) above. When the B-timer is not running, the IIS of the desired destination is stored and is transmitted in bits 14-17 together with code 1 in IDS bits 18 and 19 of the UM field unless UM use is preeempted by command from the ground. Simultaneously the B-timer is started and the code DR=1 is transmitted. The protocols of 4.13.3 then result in delivery of the message to the desired destination.

4.13.3.2 Multisite Comm-B Closeout.

Multisite Comm-B closeout is accomplished using a surveillance or Comm-A interrogation containing:

DI = 1 (multisite SD format)
IIS = Interrogator's site number
MBS = 2 (Comm-B closeout)

If IIS of the interrogation equals the stored Comm-B IIS, the stored Comm-B IIS is cleared, the B-timer is stopped, DR code 1 for this message is reset and the message itself is cancelled. If the site numbers do not match, the message is not cancelled and the states of the stored Comm-B IIS, B-timer, and DR code are not changed.

4.13.3.3 Automatic Comm-B Closeout.

If the transponder B-timer runs out before a multisite closeout is accepted, the stored Comm-B IIS is set to zero to enable this message to be read and cleared by another site.

4.13.3.4 Significance of PC Command.

When the transponder is in the multisite mode, i.e., when the IIS stored for Comm-B is not zero, receipt of a cancellation, PC=4, has no effect on the transaction unless accompanied by IIS equal to the stored Comm-B IIS.

4.13.4 Multisite Uplink ELM Protocol.

Note: The multisite Comm-C protocol augments the standard Comm-C protocol and when not in use does not modify the standard protocol described in 4.12.1.

4.13.4.1 Multisite Comm-C Reservation.

When the multisite protocol is in use, an interrogator makes a reservation for an uplink ELM by transmitting a surveillance or Comm-A interrogation containing:

DI = 1 (multisite SD format)
IIS = Interrogator's site number
MES = 1 or 5 (Comm C reservation request)
RSS = 2 (Comm C reservation status request)

Protocol procedure in response to this interrogation depends upon the state of the C-timer:

C-timer not running:

Store IIS for Comm-C
Start C-timer

C-timer running and interrogator's IIS equals Stored Comm-C IIS:

Restart C-timer

C-timer running and interrogator's IIS does not equal Stored Comm-C IIS:

No change to stored IIS or C-timer.

Note: When an interrogator asks for Comm-C reservation status and receives its own site number in the UM of the reply to a reservation interrogation, it proceeds with the delivery of the uplink ELM. Otherwise, ELM activity is not started during this scan and a new reservation request is made during the next scan.

4.13.4.2 Multisite Comm-C Delivery.

After multisite coordination is accomplished via the surveillance or Comm-A interrogation, uplink ELM delivery takes place as described in 4.12.1. In addition, the C-timer is restarted each time that a received segment is stored and the stored Comm-C IIS is not zero.

Note: The requirement for the stored Comm-C IIS to be non-zero prevents the C-timer from being restarted during a non-multisite uplink ELM transaction.

4.13.4.3 Multisite Comm-C Closeout.

Multisite Comm-C closeout is accomplished using a surveillance or Comm-A interrogation containing:

DI = 1 (Multisite SD format)
IIS = Interrogator's site number
MES = 2, 6 or 7 (Comm-C closeout)

If the stored Comm-C IIS equals the IIS of the interrogator, the uplink ELM is closed out as described in 4.12.1, the stored Comm-C IIS is cleared and the C-timer is stopped. If the site numbers do not match, the message is not cancelled and the states of the stored Comm-C IIS and the C-timer are not changed.

4.13.4.4 Automatic Comm-C Closeout.

The closeout actions described in 4.13.4.3 are initiated automatically when the C-timer runs out.

4.13.4.5 Significance of PC Command.

When the transponder is in the multisite mode, i.e., when the IIS stored for Comm-C is not zero, receipt of a cancellation, PC=5, has no effect on the transaction unless accompanied by IIS equal to the stored Comm-C IIS.

4.13.5 Multisite Downlink ELM Protocol.

Note: The multisite Comm-D protocol augments the standard Comm-D protocol and when not in use does not modify in any way the standard protocol described in 4.12.2.

4.13.5.1 Multisite Comm-D Reservation.

When the multisite protocol is in use, an interrogator makes a reservation for ground initiation of a Comm-D message transfer by transmitting a surveillance or Comm-A interrogation containing:

DI = 1 (multisite SD format)
IIS = Interrogator's site number
MES = 3 or 6 (Comm D reservation request)
RSS = 3 (Comm D reservation status request)

Protocol procedure in response to this interrogation depends upon the state of the D-timer:

D-timer not running:

Store IIS for Comm-D
Start D-timer

D-timer running and interrogator's IIS equals Stored Comm-D IIS:

Restart D-timer

D-timer running and interrogator's IIS does not equal Stored Comm-D IIS:

No change to stored IIS or D-timer.

Note: When an interrogator asks for Comm-D reservation status and receives its own site number in the UM of the reply to a reservation interrogation, it proceeds to request delivery of the downlink ELM. Otherwise, ELM activity is not started during this scan and a new reservation request may be made during the next scan.

4.13.5.1.1 Multisite Directed Comm-D Transmissions.

If the airborne data system needs to direct a Comm-D ELM message to a specific interrogator, a procedure corresponding to the directed Comm-B protocol (4.13.3.1.1) can be used. In effect a "self reservation" is accomplished by storing the IIS of the desired site destination and proceeding with the usual protocol.

The stored IIS can be transmitted in bits 14-17 together with code 3 in IDS bits 18 and 19 of the UM field unless UM use is preempted by command from the ground. The DR code is set according to 4.12.2.1.

4.13.5.2 Multisite Comm-D Delivery.

After multisite coordination is accomplished via the surveillance or Comm-A interrogation, downlink ELM delivery takes place as described in 4.12.2. In addition, the D-timer is restarted each time that a request for Comm-D segments is received while the stored Comm-D IIS is non-zero.

> *Note: The requirement for the stored Comm-D IIS to be non-zero prevents the D-timer from being restarted during a standard downlink ELM transaction.*

4.13.5.3 Multisite Comm-D Closeout.

Multisite Comm-D closeout is accomplished using a surveillance or Comm-A interrogation containing:

DI = 1 (Multisite SD format)
IIS = Interrogator's site number
MES = 4, 5, or 7 (Comm-D closeout)

If the stored Comm-D IIS equals the IIS of the interrogator, the downlink ELM is closed out as described in 4.12.2, the stored Comm-D IIS is cleared and the D-timer is stopped. If the site numbers do not match, the message is not cancelled and the states of the stored Comm-D IIS, the D-timer, and the DR code are not changed.

4.13.5.4 Automatic Comm-D Closeout.

If the D-timer runs out, the stored Comm-D IIS is set to zero. The Comm-D message and the DR field are not cleared. This makes it possible for another site to read and clear the Comm-D message.

4.13.5.5 Significance of PC Command.

When the transponder is in the multisite mode, i.e., when the IIS stored for Comm-D is not zero, receipt of a cancellation, PC=6, has no effect on the transaction unless accompanied by IIS equal to the stored Comm-D IIS.

4.13.6 Multisite Lockout Protocol.

Note: To prevent transponder acquisition from being denied to one interrogator by lockout commands originating from another interrogator the multisite All-Call lockout is used. The Mode S-only All-Call interrogation includes an interrogator identity code. If this code matches one previously set in a multisite lockout command, the transponder does not reply. (The Non-Selective All-Call lockout (4.3.1) is independent of this protocol).

4.13.6.1 Multisite All-Call Lockout Initiation.

The multisite lockout command is transmitted in the SD field (4.13.1.1). The command for this lockout is indicated by code LOS=1 and the presence of a non-zero site address in the IIS subfield of SD. The lockout persists for an interval T_L (5.4.6) after the last acceptance of an interrogation containing the command but can be overriden by the PR codes 8 through 12.

Note: Fifteen interrogators can send independent multisite lockout commands. Each of these must be timed independently.

4.13.6.2 Multisite All-Call Lockout Function.

After a transponder has accepted an interrogation containing a multisite lockout command, that transponder rejects all Mode S-Only All-Call interrogations which include in the II field (3.3.11) the site number of the interrogator that commanded the lockout.

Note: Multisite lockout does not affect the response of the transponder to Mode S-Only All-Call interrogations with II=0 or to ATCRBS/Mode S All-Call interrogations.

4.14 Flight Identification Reporting.

A data request per 4.11.1 containing RR=18 elicits a reply containing the flight identification in the MB field.

4.14.1 FIS Flight Identification Subfield in MB.

If a surveillance or Comm-A interrogation (UF=4, 5, 20, 21) contains RR=18 and DI other than 7, the transponder will report its flight identification number in the 48-bit (41-88) FIS subfield of MB. Coding assignments are not included in this standard; see the note at 5.6.1.1.

4.15 Broadcast Protocol.

The broadcast interrogation data (4.2.1.2) are presented at the transponder output data interface. No reply is required (4.2.2.4.1) and other transponder functions are not affected.

> *Note: This paragraph prevents protocol (lockout) changes if broadcast is used.*

4.16 All-Call Reply Protocol.

The Mode S-only All-Call interrogation UF=11 contains the interrogator identifier in the II field. The content of this field is overlaid on parity according to 4.1.2, resulting in the PI field of the reply DF=11.

Receipt of an ATCRBS/Mode S All-Call interrogation automatically implies that the interrogator identifier is zero.

A reply will be made to an accepted All-Call: 3.3.23, 4.2.2.4.4.

4.17. TCAS Protocols.

TCAS uses the formats UF=DF=0, 16 for air-to-air communications.

4.17.1 AQ, RI, RL, VS Protocol.

On receipt the special interrogations UF=0, UF=16, the transponder follows the rules of:

AQ (3.3.4)
RI (3.3.25)
RL (3.3.26)
VS (3.3.31)

5. TRANSPONDER CHARACTERISTICS.

This section describes the technical characteristics of the Mode S transponder.

5.1 Interrogation Acceptance Criteria.

Mode S transponders accept ATCRBS mode A and mode C interrogations in accordance with the provisions of ref. A with the following exception: Mode S transponders do not accept a waveform as an ATCRBS interrogation if the P_3 pulse is followed by a valid P_4 pulse (2.3.2). However, if a valid ATCRBS waveform is followed by a pulse with a leading edge within 1.95 to 2.05 after P3, but the level of said pulse is more than 6 dB below the level of P_3, the waveform is accepted by the Mode S transponder as an ATCRBS interrogation.

> *Note: The Mode S transponder does not generate a reply of any type on receipt of an ATCRBS-only All-Call interrogation (short P_4). This allows Mode S transponders to be removed from the ATCRBS reply population in synchronous garble situations. The Mode S transponder generates a Mode S reply on acceptance of an ATCRBS/Mode S All-Call interrogation (long P_4).*

5.1.1 Mode S Interrogation Acceptance.

5.1.1.1 Pulse Level Tolerances.

Mode S transponders do not accept a waveform as an ATCRBS/Mode S All-Call (2.3.2) if the level of the pulse in the P_4 position is more than 6 dB below the level of P_3.

5.1.1.2 Pulse Position Tolerances.

Mode S transponders do not accept a waveform as an ATCRBS/Mode S All-Call (2.3.2) if either: a) the leading edge of P_4 is not detected within the interval from 1.7 to 2.3 microseconds following the leading edge of P_3, or b) the trailing edge of P_4 is detected earlier than 3.3 or later than 4.2 microseconds after the leading edge of P_3.

> *Note: The Mode S transponder looks for a leading edge rather than energy in the stated interval. Thus it does not generate an All-Call reply on receipt of an ATCRBS interrogation with a very wide P_3 pulse or on receipt of an All-Call interrogation without space between P_3 and P_4. However, the Mode S transponder may generate the appropriate ATCRBS reply to such an interrogation.*

5.1.1.3 Pulse Duration Tolerances.

Mode S transponders do not accept a waveform as an ATCRBS/Mode S All-Call (2.3.2) if the received amplitude of P_1 or P_3 is between MTL and at least 45 dB above MTL and the duration of P_1 or P_3 is less than 0.3 microsecond.

5.1.1.4 Sync Phase Reversal Position Tolerance.

For signal levels between MTL and -21 dBm Mode S transponders

a. accept a waveform if the sync phase reversal is detected at its nominal location plus or minus 0.05 microseconds.

b. do not accept a waveform if the sync phase reversal is not detected at its nominal position plus or minus 0.15 microseconds.

Note: Non-detection of the sync phase reversal occurs when the received pulse is not actually a P_6 pulse of the Mode S interrogation waveform or if the sync phase reversal of an actual P_6 is deliberately masked while in the sidelobe of the interrogator by receipt of a P_5 Mode S-SLS pulse.

5.1.1.5 Data Overflow.

Mode S transponders do not accept long interrogations while their respective data storage limits (5.6.2.3.1) are exceeded.

5.2 Transponder Sensitivity and Dynamic Range.

Transponder sensitivity is defined in terms of a given signal input level at the antenna terminal of the installation and a given percentage of corresponding replies. Only correct replies containing the proper bit pattern for the interrogation received are counted. Given an interrogation which requires a reply according to 4.2, the minimum triggering level, MTL, is defined as the minimum input power level for 90% reply to interrogation ratio. MTL is -74 dBm ±3 dB. The reply to interrogation ratio of a Mode S transponder is:

a. at least 99% for signal input levels between (MTL + 3 dB) and -21 dBm

b. no more than 10% at signal input levels below -81 dBm

Note: Transponder sensitivity as well as output power are described in this document in terms of signal level at the terminals of the antenna. This gives the designer freedom to arrange the installation, compromising between cable length and receiver-transmitter design and does not exclude receiver and/or transmitter components from becoming an integral part of the antenna subassembly.

5.2.1 Sensitivity in the Presence of Interference.

Note: The principal interfering signals in space are ATCRBS waveforms. Since the technical characteristics of these signals are well defined, Mode S transponders can be designed to be as immune to them as possible. The use of the DPSK modulation scheme on the uplink provides inherent interference rejection capability. Proper design of the Mode S demodulator provides additional immunity to false mode decodes. The following paragraphs present measures of the performance of the Mode S transponder in the presence of common interference signals.

5.2.1.1 Reply Ratio in the Presence of a Standard Interfering Pulse.

A standard interfering pulse is defined as a 0.8 microsecond pulse of 2.2.1.1 with a carrier frequency of 1030 ±0.2 MHz which is incoherent with the Mode S signal and which overlaps the P_6 of the Mode S interrogation anywhere after the sync phase reversal.

Given an interrogation which requires a reply (4.2), the reply ratio of a transponder is at least 95 percent if the level of the interfering pulse is 6 dB or more below the signal level for input signal levels between -68 and -21 dBm.

Under the same conditions the reply ratio is at least 50 percent if the interference pulse level is 3 dB or more below the signal level.

Note: This simulates the overlay of ATCRBS pulses over the DPSK modulation of the Mode S interrogation and assures that the demodulation scheme of the transponder is effective. Designs such as narrow band filters which merely detect the occurrence of a phase change will not give the desired reply ratio.

5.2.1.2 Reply Ratio in the Presence of Pulse Pair Interference.

The interfering signal consists of P_1 and P_2, spaced 2 microseconds apart with a carrier frequency of 1030 ±0.2 MHz which is incoherent with the Mode S signal. The interfering pulse pair overlays any part of the Mode S interrogation except that the leading edge of the P_1 interfering pulse occurs no earlier than the P_1 pulse of the Mode S signal. Given an interrogation which requires a reply (4.2), the reply ratio of a transponder is at least 90 percent if the level of the interfering signal is 9 dB or more below the signal levels for signal level inputs between -68 and -21 dBm.

Note: This assures that Mode S decoding is not inhibited by the receipt of ATCRBS sidelobe suppression pulse pairs.

5.2.1.3 Reply Ratio in the Presence of Low Level Asynchronous Interference.

For all received signal levels between -65 dBm and -21 dBm and given a Mode S interrogation that requires a reply and if no lockout condition is in effect a Mode S transponder replies correctly with at least 95% reply ratio in the presence of asynchronous interference.

Asynchronous interference consists of single 0.8 microsecond pulses with carrier frequency of 1030 MHz, incoherent with the Mode S signal carrier frequency and occuring at all repetition rates up to 10,000 Hz at a level 12 dB or more below the level of the Mode S signal.

> *Note: Such pulses may combine with the P_1 and P_2 pulses of the Mode S waveform to form a valid ATCRBS-only All-Call pattern. The Mode S transponder does not reply to ATCRBS-only All-Calls. A preceding pulse may also combine with the P_2 of the Mode S waveform to form valid Mode A or Mode C patterns. Under such conditions, the P_1 - P_2 pair of the Mode S preamble takes precedence.*

5.3 Transponder RF Peak Output Power.

The peak RMS rf output power of each pulse of a reply, measured at the terminals of the antenna is:

Minimum rf power for aircraft operating at altitudes not exceeding 15,000 ft:	18.5 dBW
Minimum rf power for aircraft which operate above 15,000 ft:	21.0 dBW
Minimum rf power for aircraft with normal cruising speed in excess of 175 knots:	21.0 dBW
Maximum rf power for all aircraft:	27.0 dBW

5.3.1 Unwanted Transponder Output Power.

When the transponder transmitter is in the inactive state, the RF output power at 1090 ± 3 MHz at the terminals of the antenna does not exceed -50 dBm. The inactive state is defined to include the entire period between ATCRBS and/or Mode S transmissions less 10-microsecond transition periods, if necessary, preceding and following the extremes of the transmission.

> *Note: Off-state transponder power is constrained in this way to insure that an aircraft when located as near as 0.1 nmi to an ATCRBS or Mode S sensor does not cause interference to that installation. In certain applications of Mode S, TCAS for example, where 1090 MHz transmitter and receiver are in the same aircraft, it may be necessary to further constrain the off-state transponder RF power.*

5.4 Special Characteristics.

5.4.1 Dead Time.

Dead time is the time interval beginning at the end of a reply transmission and ending when the transponder has regained sensitivity to within 3 dB of MTL. Transponders do not have more than 125 microseconds dead time.

5.4.2 Recovery Time, Definition.

Recovery time is the time interval beginning at the end of a received signal and ending when the transponder sensitivity has recovered to within 3 dB of MTL provided that no reply is to be made in response to the received signal.

5.4.2.1 Recovery.

All transponder recoveries are as prescribed in ref. A.

5.4.2.2 Mode S Receiver Desensitization.

On receipt of any pulse of more than 0.7 microsecond duration, the transponder's receiver is desensitized according to ref. A, 2.7.7.1. The transponder recovers sensitivity at the rate described in ref. A, 2.7.7.2.

5.4.2.3 Recovery from a Mode S Interrogation.

Following an incorrectly addressed Mode S interrogation a transponder recovers sensitivity at the rate described in ref. A, 2.7.7.2.

5.4.2.4 Recovery from a Mode S Interrogation if no Reply is Required.

Following a Mode S interrogation other than Comm-C, UF=24, which has been accepted and which requires no reply, a transponder recovers sensitivity, starting not later than 128 microseconds after receipt of the sync phase reversal at the rate prescribed for recovery times in ref. A, 2.7.7.2.

5.4.2.5 Recovery from a Mode S Comm-C Interrogation.

Following a Comm-C interrogation for which no reply is required, a transponder recovers sensitivity, starting no later than 31 microseconds after receipt of the sync phase reversal at the rate prescribed for recovery times in ref. A.

5.4.2.6 Recovery from an ATCRBS Suppression Pair.

The receipt of P_1 and P_2 suppression pulses may temporarily desensitize the transponder according to 5.4.2.2 but ATCRBS suppression pairs do not otherwise interfere with the reception of Mode S interrogations.

5.4.3 Unwanted Mode S Replies.

In the absence of valid interrogation signals, Mode S transponders do not generate unwanted Mode S replies more often than once in 10 seconds.

5.4.4 Reply Rate Limiting.

Reply rate limiting is handled separately for ATCRBS and for Mode S.

5.4.4.1 Mode S Reply Rate Limiting.

Reply rate limiting is not required for the Mode S formats of a transponder. If such limiting is incorporated for circuit protection, it must permit the minimum reply rates required in 5.4.5.

5.4.4.2 ATCRBS Reply Rate Limiting.

Reply rate limiting for ATCRBS is effected according to ref. A, 2.7.10. The prescribed sensitivity reduction (ref. A, 2.7.10.3) does not affect the Mode S performance of the transponder.

5.4.5 Minimum Peak Reply Rates.

5.4.5.1 ATCRBS Minimum Peak Reply Rate.

The minimum peak reply rate for ATCRBS is as described in ref. A: 2.7.10.1, 2.7.10.2.

5.4.5.2 Mode S Minimum Peak Reply Rates.

A transponder transmitting short and long replies but not transmitting ELM downlink sequences can generate as long replies at least:

16 of 50 Mode S replies in any one second interval
6 of 18 Mode S replies in a 100-millisecond interval
4 of 8 Mode S replies in a 25-millisecond interval
2 of 4 Mode S replies in a 1.6 millisecond interval

At least once every four seconds a Mode S transponder equipped for ELM downlink operation is capable of transmitting, in a 25-millisecond interval, 25% more segments than have been announced in the initialization (4.12.2.1).

Note: Transponders may exist which are capable of transmitting less than the maximum allowable number of Comm-D segments in one burst. The requirement for 25% surplus transmitting capacity is derived from the possible need for re-interrogation.

5.4.6 Timers.

Duration and features of timers are shown below.

Timer			Duration		Tolerance	Reset
Name	Number	Para.	Symbol	Sec.	Sec.	?
Non-selective All-Call Lockout	1	4.3.1	T_D	18	±2	no
Temporary Alert	1	4.5.1.2	T_C	18	±2	no
SPI	1	4.5.3	T_I	18	±2	no
Reservations B,C,D	3*	4.13.2.1	T_R	18	±2	yes
Multisite Lockout	15	4.13.6.1	T_L	18	±2	no

*As required.

Note: The tolerance specified for the timers makes it possible to implement the timing system with a single asynchronous clock operating in 4 second cycles.

5.5 Diversity Operation.

Diversity Mode S transponders have two RF ports for operation with two antennas, one antenna on the top and the other on the bottom of the aircraft's fuselage. The received signal from one of the antennas is selected for acceptance and the reply is transmitted from the selected antenna.

5.5.1 Antenna Selection.

The transponder automatically selects one of the two antennas on the basis of the relative strengths of the detected interrogation signals if both channels receive simultaneously a valid interrogation or pulse pair. Antenna selection and switching may occur after the receipt of:

a. The P_3 pulse of an ATCRBS or ATCRBS/Mode S All-Call interrogation, or
b. The P_2 pulse of a $P_1 - P_2$ pair, indicating a possible Mode S preamble, or
c. The first microsecond of a P6, or
d. A complete, error-free Mode S interrogation.

The selected antenna is used for the reception of the remainder of the interrogation and for transmission of the reply.

5.5.1.1 Selection Threshold.

The transponder selects the antenna connected to the RF port having the stronger signal. In a plus or minus 3 dB wide differential grey zone either antenna can be selected. Antenna selection is carried out at all received signal levels from MTL to -21 dBm.

Correctness of a received complete Mode S interrogation can be used as a selection criterion such that the antenna with the correct signal is selected. If correctness is observed in both channels the antenna is selected on the basis of received signal strengths.

5.5.1.2 Received Signal Delay Tolerance.

If an interrogation is received at either antenna 0.125 microseconds or less in advance of reception at the other antenna, the interrogations are considered simultaneous and the reply antenna selection criteria applied. If an interrogation is received at either antenna 0.375 microseconds or more in advance of reception at the other antenna, the antenna selected for the reply is that which received the earlier interrogation. If the relative time of receipt is between 0.125 and 0.375 microseconds, the transponder selects the antenna for reply either on the basis of the simultaneous interrogation criteria or on the basis of the earlier time of arrival.

5.5.2 Diversity Transmission Channel Isolation.

The peak rf power transmitted from the selected antenna exceeds the power transmitted from the not-selected antenna by at least 20 dB.

5.5.3 Reply Delay of Diversity Transponders.

The total difference in mean reply delay between the two antenna channels (including the transponder-to-antenna cables) does not exceed 0.08 microseconds for interrogations of equal amplitude. This applies to interrogation signal strengths between MTL+3 dB and -21 dBm.

Note: This limits apparent jitter caused by antenna switching and by cable delay differences. The jitter performance on each individual channel remains as described for non-diversity transponders. Apparent jitter caused by antenna location is limited by 5.7.3.

5.6 Data Handling and Interfaces.

5.6.1 Direct Data.

Direct data are those which are part of the surveillance protocol of the Mode S system.

5.6.1.1 Fixed Direct Data.

Fixed direct data characterize the aircraft and are:

a. The Mode S address (3.3.1)
b. The maximum airspeed (3.3.25)
c. The flight identification data (4.14)

Note: The flight identification number for some aircraft is the "Tail Number" or registration number of the aircraft. This number is used in communication with air traffic control and it never changes. It is thus classified as "fixed direct data". Other aircraft report their "flight number" rather than their registration number. The flight number changes frequently and is thus classified as "variable" direct data (5.6.1.3). Coding for the Mode S address and the flight identification data is not included in this Standard.

5.6.1.2 Interfaces for Fixed Direct Data.

Interfaces from the transponder to the aircraft may be provided such that the values of the fixed direct data become a function of the aircraft installation rather than of transponder configuration.

Note: The intent of this paragraph is to encourage a connector system which permits transponder exchange without manipulation of the transponder itself for setting the fixed direct data.

5.6.1.3 Variable Direct Data.

Variable direct data characterize the flight condition of the aircraft and are:

a. the pressure altitude (3.3.2)
b. the 4096 identification code (3.3.10)
c. the on-the-ground condition (3.3.9; 3.3.31)
d. the flight identification data number (4.14)
(also see note at 5.6.1.1)
e. the SPI condition (4.5.3)

5.6.1.4 Interfaces for Variable Direct Data.

The 4096 identification code, the SPI condition, and the variable flight identification data or "flight number" values are inserted by the pilot.

Interfaces are included to accept the pressure altitude and on-the-ground codes.

Note: A specific interface design for the variable direct data is not prescribed in this Standard.

5.6.2 Indirect Data.

Indirect data are those which pass through the transponder in either direction but which do not affect the surveillance function.

If sinks and/or sources of such data are not within the transponder's enclosure, interfaces will be used for the necessary connections.

5.6.2.1 Integrity of Data Content Transfer.

A transponder which employs data interfaces includes sufficient protection to assure error rates of less than one error in 10^3 messages and less than one undetected error in 10^7 messages in both directions between the antenna(s) and the interface port(s).

5.6.2.2 The Function of Interfaces.

Indirect Data Interfaces for Standard Transactions serve interrogations which require reply and the broadcast function. Indirect Data Interfaces for ELM serve that system and require buffering and protocol circuitry within the transponder.

5.6.2.2.1 Uplink Standard Transaction Interface.

The uplink standard transaction interface transfers all bits, with the possible exception of the Address/Parity field AP of all accepted interrogations.

Note: AP transfer aids in integrity implementation.

5.6.2.2.2 Downlink Standard Transaction Interface.

A transponder which transmits information originating in a peripheral device is able to insert bits or bit patterns at appropriate locations within the transmission. These locations do not include the locations of bit patterns generated by the transponder internally or of the address/parity field of the reply.

Note: Examples are the content of the DR, FS and UM fields.

A transponder which transmits information using the Comm-B format, has immediate access to requested data in the sense the transponder responds to an interrogation with data requested by that interrogation. This requirement can be met in either of two ways:

a. the transponder may have provisions for internal data and protocol buffering,

b. the transponder may employ a "real time" interface which operates such that uplink data leave the transponder before the corresponding reply is generated and downlink data enter the transponder in time to be incorporated in this reply.

5.6.2.2.3 The Extended Length Message Interface.

The ELM interface extracts from and enters into the transponder the data exchanged between air and ground by means of the ELM protocol (4.12). ELM messages employ bursts of Comm-C and Comm-D transmissions and therefore the message contents must be buffered within the transponder.

5.6.2.3 Indirect Data Transaction Rates.

5.6.2.3.1 Standard Transactions.

A transponder equipped for information transfer to and from external devices is capable of handling the data of at least as many interrogations and replies as prescribed for minimum reply rates in 5.4.5.

A transponder capable of reply rates larger than the minimum of 5.4.5. may not accept long interrogations after reaching the limits of 5.4.5.

Note: The Mode S reply is the sole means of acknowledging receipt of the data content of a Mode S interrogation. Thus if the transponder is capable of replying to an interrogation, the airborne data system must be capable of accepting the data contained in that interrogation regardless of the timing between it and other accepted interrogations. Overlapping Mode S beams from several interrogators could lead to the requirement for considerable data handling and buffering. The minimum described here reduces data handling to a realistic level and the non-acceptance provision provides for notification to the interrogator that data will temporarily not be accepted.

5.6.2.3.2 ELM Transactions.

A transponder equipped for ground-to-air ELM operation can handle the data of at least one complete 16-segment ELM (4.12.1) in a four second period. A transponder equipped for air-to-ground ELM operation, can handle at least one 4-segment air-to-ground ELM (see 5.4.5.2 and 4.12.2.2) in a four second period.

5.7 Transponder Antenna System.

Transponder antennas are mounted on the fuselage of the aircraft such that obstructions to their field in the horizontal plane are minimized.

If only one antenna is used, it is located on the bottom center line of the fuselage; the second antenna, used for diversity transponders, is mounted on the top of the fuselage.

5.7.1 Polarization.

Mode S antennas are vertically polarized.

5.7.2 Radiation Pattern.

The radiation pattern of Mode S antennas when installed on an aircraft is nominally equivalent to that of a quarter-wave monopole on a ground plane.

Note: Transponder antennas designed to increase gain at the expense of vertical beamwidth are undesirable because of their poor performance during turns.

5.7.3 Antenna Location.

The horizontal distance between the top and the bottom antennas is not greater than 7.6 meters. Both antennas are mounted as near as possible to the center line of the fuselage.

6. INTERROGATOR CHARACTERISTICS.

This section describes salient technical characteristics of the Mode S interrogator.

Note: To assure that Mode S interrogator action is not injurious to the radar beacon system, performance limits exist for Mode S interrogators.

6.1 Interrogation Repetition Rates.

Mode S interrogators use the lowest practicable interrogation repetition rates for all interrogation modes.

6.1.1 ATCRBS/Mode S All-Call Interrogation Repetition Rate.

The interrogation repetition rate for the ATCRBS/Mode S All-Call, used for acquisition, is less than 150 per second.

6.1.2 Interrogation Repetition Rate to a Single Aircraft.

Mode S interrogations requiring a reply are transmitted to a single aircraft in intervals not shorter than 400 microseconds.

6.1.3 Repetition Rate for Discrete Interrogations.

The interrogation rate for Mode S uplink formats is:

a. less than 1165 per second averaged over a 4 second interval
b. less than 1840 per second averaged over a 1 second interval
c. less than 2400 per second averaged over a 40 millisecond interval

Note: The interrogation rate above depends on the number of Mode S transponders within the coverage volume of the interrogator. If there are no Mode S transponders in this volume, the interrogation rate is zero. The rates given above are based on the following assumptions considering absolute worst-case traffic loading and bunching for a rotating antenna interrogator with a 4 second/360° scan rate:

Scan Angle	*No. of Aircraft*	*Interrogations Per Aircraft*		*Total No. of Interrogations*	*Period (sec)*	*Rate (sec^{-1})*
360°	*700*	*3 long*		*2100*		
	+160	*16 ELM*		*2560*		
			Total	*4660*	*4.*	*1165*
90°	*400*	*3 long*		*1200*		
	+40	*16 ELM*		*640*		
			Total	*1840*	*1.*	*1840*
3.6°	*48*	*2 long*		*96*	*0.04*	*2400*

6.2 Interrogator RF Peak Output Power.

The maximum effective radiated peak power of all interrogation pulses is as described in ref. A, 2.8.2.1.

Note: Ref. A permits up to 52.5 dBW which includes antenna gain and transmission losses.

6.3 Unwanted Interrogator Output Power.

When the interrogator transmitter is not transmitting an interrogation, its output does not exceed -5 dBm effective radiated power at any frequency.

Note: This constraint assures that aircraft flying near the interrogator (as close as 1 nmi) do not receive interference that would prevent their being tracked by another interrogator. In certain instances even smaller interrogator-to-aircraft distances are of significance, for example if Mode S surveillance on the airport surface is used. In such cases a further restraint on off-state interrogator output power may be necessary.

6.4 Tolerances on Transmitted Waveforms.

In order that the signal in space is received by the transponder as described in section 2, the tolerances on the transmitted signal are as summarized in the following table:

Paragraph	Function	Tolerance
2.2.1.1	Pulse Duration P1,P2,P3,P4,P5	± 0.09 microseconds
	Pulse Duration P6	± 0.02 microseconds
2.3.2.1	Pulse Position P1-P3	± 0.18 microseconds
	Pulse Position P1-P2	± 0.10 microseconds
	Pulse Position P3-P4	± 0.04 microseconds
2.3.3.4	Pulse Position P1-P2	± 0.04 microseconds
	Pulse Position P2-Sync. Ph. Rev	± 0.04 microseconds
	Pulse Position P6-Sync. Ph. Rev	± 0.04 microseconds
	Pulse Position P5-Sync. Ph. Rev	± 0.05 microseconds
Ref.A, 2.5	Pulse Amplitudes : P3 = P1 ± 0.5 dB	
2.3.2.2	Pulse Amplitudes : P4 = P3 ± 0.5 dB	